Influence of single post, oval, and multi-post restorative techniques and amount of residual tooth substance on fracture strength of endodontically treated maxillary premolars

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Abstract

Purpose: The aim of this study was to compare the influence of the number of coronal walls and post-endodontic restorations on the mechanical strength of 165 recently extracted endodontically treated maxillary premolars.

Methods: The teeth were divided into 3 control (no post) and 3 test groups according to the number of residual walls. Each test group was divided into subgroups according to the type of post-endodontic restoration (single, oval, and multi-post techniques). Samples were prepared conforming to the assigned subgroup. A universal loading machine applied a load parallel to the longitudinal axis of the teeth, thus simulating physiological occlusion. ANOVA and the Kruskal Wallis test were used for comparisons ($P \le 0.05$), and Tukey's test for multiple comparisons.

Results: For intact teeth, significant differences were found among all 3 subgroups, with single post showing the highest values. For 3 residual walls, oval post resulted in significantly lower values than single and multi-post systems. For 2 residual walls, the multi-post technique showed almost twice the resistance of oval post restorations.

Conclusion: In oval canals the use of a single or multi-post technique increased post-and-core resistance even in intact teeth, whereas oval fiber posts showed no improvements. Multi-post design improved fracture resistance mostly in maxillary premolars lacking both marginal ridges.

Keywords; fracture strength, multi-post, oval post, post-endodontic restoration, single post

Introduction

Restoration of endodontically treated teeth (ETT) represents a critical issue in restorative and prosthetic dentistry [1]. In recent years, intracanal posts were proposed in order to reduce the failure rate of post-endodontic restorations. Their use increases the retention of coronal restorations as well as the fracture resistance of residual dental substance [2]. Therefore, in order to reduce the occurrence of unrestorable root fracture, posts with mechanical characteristics similar to those of dentine have been suggested [2]. Carbonfiber posts guarantee better stress distribution along root canal surfaces [3]; their mechanical characteristics are maintained when substituted by fiberglass posts for esthetic reasons. Due to the similarity of their elasticity moduli-and therefore their more homogeneous stress distribution-fiber posts are effective in reducing the fracture incidence of ETT [4-6]. In particular, maxillary premolars are more prone to fracture risk because of their anatomical features and position in the dental arch [7,8]. Two studies [9,10] have provided evidence that endodontically treated premolars restored with fiber posts have an increased survival rate, especially when they have lost 4 coronal walls. In a retrospective study of 200 patients,

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Ferrari et al. [8] noted a success rate of 95% for a composite system and 84% for a cast post-and-core system after 4 years of clinical service. With cast post-and-cores, most of the observed failures were due to root fracture, whereas with fiber post restorations, failures were mostly due to post decementation, possibly as a consequence of the high C-factor recorded within the root canal. Moreover, Sorrentino et al. [10] demonstrated that fiber post placement in premolars that have lost at least one wall reduced the occurrence of unfavorable and unrestorable fractures. Several studies have investigated the possibility of adding accessory posts to a master post [11] or customizing the shape of intracanal posts to root canal anatomy [12]. Although these techniques actually improve post-fitting, especially in non-circular root canals, they require clinical experience and increase the operating time. In order to achieve conservative post-space preparation in oval-shaped canals, oval fiberglass posts used in combination with oval ultrasound tips have recently been introduced [2,13].

So far, few data are available regarding the fracture resistance of different post-endodontic restorations proposed over recent years. Therefore, the aim of the present *ex vivo* study was to compare the mechanical strength of single-rooted endodontically treated maxillary premolars with different numbers of residual coronal walls and different post-endodontic restorations: single post, oval post and multi-post. The null hypothesis tested was that there would be no statistically significant differences in the fracture resistance of endodontically treated single-rooted maxillary premolars with different amounts of residual dental substance and different types of post-endodontic restoration.

Materials and Methods

Sample selection and preparation

After obtaining approval from the local ethics committee (protocol number #16894) and informed consent from the patients concerned, 165 recently extracted intact human single-rooted maxillary premolars were included in the study. After cleaning of remaining tissues, a ×4.5 stereomicroscope (Nikon SMZ645; Nikon, Tokyo, Japan) was employed to rule out any external radicular cracks. Samples were stored in 0.9% saline solution (SALF SPA, Cenate Sotto, Italy) at a temperature of 37°C to prevent dehydration. Preoperative standardized radiographs were taken to confirm the presence of a single straight canal and absence of previous restorative or endodontic treatments. The bucco-lingual and mesio-distal dimensions of each crown, as well as the distance between the cemento-enamel junction (CEJ) and the occlusal surface were recorded with a digital caliper (Tchibo, Hamburg, Germany) and used to distribute samples homogeneously into 3 control and 3 test groups. Each test group was divided into 3 subgroups according to the type of post-endodontic restoration (Table 1).

Oval-shaped access cavities reflecting the anatomy of the pulp chamber were realized by a single operator. In group 2, the mesial wall was removed, whereas both the mesial and distal walls were removed in group 3, creating mesio-occluso-distal (MOD) cavities.

Endodontic treatment

Chemo-mechanical preparation was performed by the same operator using reciprocating instruments (Reciproc R25; Dentsply-VDW, Munich, Germany). Irrigation was carried out with 5.25% NaOCl during instrumentation and a final flush of 17% EDTA followed by 5.25% NaOCl. After

Table 1 Control groups and test groups

[§] Group	Residual walls	Restoration	
Control 0	4 (<i>n</i> = 10)		
Control 02	3 (<i>n</i> = 10)	no post	
Control 0 ₃	2 (<i>n</i> = 10)		
		A1: single post	
Test 1	4 (<i>n</i> = 45)	B1: oval post	
		C ₁ : multi-post	
		A2: single post	
Test 2	3 (<i>n</i> = 45)	B2: oval post	
		C ₂ : multi-post	
		A ₃ : single post	
Test 3	2 (<i>n</i> = 45)	B ₃ : oval post	
		C ₃ : multi-post	

Groups are listed according to the number of residual walls (1, 2, and 3) and according to the type of postendodontic restoration (A, B, and C). For control groups, no post system was used.
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Fig. 1 Occlusal and lateral views of 3 single-rooted maxillary premolars restored with one D.T. Light-Post Illusion X-RO #0.5 (a), 1 RTD Macro-Lock OVAL Post #1(b) and 2 D.T. Light-Post Illusion X-RO #0.5 (c)

Materials	Characteristics	Composition
D.T. Light-Post Illusion X-RO #0.5	tip diameter 0.80 mm	thermomimetic quarz fiber X-RO
(Dental Trey, Dentsply srl, Rome, Italy)	head diameter 1.25 mm	silica based chemical formulation
	taper 0.4	epoxy resin matrix
RTD Macro-Lock OVAL Post #1	tip diameter 0.80 mm	radiopaque quartz fibers
Dental Trey, Dentsply srl)	head diameter 2.17 mm	epoxy resin matrix
	taper 0.4 apical segment	catalyst
	profoundly flared coronal section	colored pigment
DeTrey Conditioner	etching gel	36% phosphoric acid
Dentsply Sirona, Weybridge, UK)		highly dispersed silicon dioxide
		detergent
		pigment
		water
Prime & Bond NT Dual-Cure	Light Cure/Self Cure use adhesive system	di- and trimethacrylate resins
Dentsply Sirona)		PENTA (dipentaerythritol penta acrylate monophosphate
		stabilizers
		photoinitiators
		nanofillers-amorphous silicon dioxide
		cetylamine
		hydrofluoride
		acetone based
Core-X Flow	core build-up and post cementation material	syringe with mixing tips
Dental Trey, Dentsply srl)		two components, base and catalyst
		highly filled (69.1%)
		dual cured
KP-Bond	Universal Total-Etch Adhesive	carboxylic acid modified dimethacrylate (TCB resin)
Dentsply srl)		phosphoric acid modified acrylate resin (PENTA)
		urethane dimethacrylate (UDMA)
		triethyleneglycol dimethacrylate (TEGDMA)
		2-hydroxyethylmethacrylate (HEMA)
		butylated benzenediol (stabilizer)
		ethyl-4-dimethylaminobenzoate; camphorquinone
		functionalized amorphous silica
Ceram-X Duo E2	nano hybrid composite with pre-polymerized fillers	sphereTEC fillers (≈15 µm)
Dentsply srl)		non-agglomerated barium glass fillers (~0.6 µm)
		ytterbium fluoride (≈0.6 µm)
		highly dispersed, methacrylic polysiloxane nano-particles

drying with paper points, canal obturation was achieved through the continuous condensation wave technique. Obturation with gutta-percha was performed using Reciproc blue R25 master cones and root canal sealer (AH Plus Root Canal Sealer; Dentsply DeTrey, Konstanz, Germany) using the BeeFill 2 in 1 device (VDW, GmbH, Munich, Germany) with a small heat carrier (#40 tip size and .03 taper) in accordance with the manufacturer's instructions. After the down-packing phase, back-filling was performed with the same device and manual compaction was done using endodontic pluggers (Machtou 1-2 and 3-4; Dentsply Sirona, York, PA, USA).

Post-endodontic restoration

For the A (single post) and C (multipost) subgroups, double-taper shaped posts (D.T. Light-Post Illusion X-RO #0.5; Dental Trey, Dentsply srl, Rome, Italy) were used. For the B subgroups, oval posts (RTD Macro-Lock OVAL Post #1; Dental Trey, Dentsply srl) were used (Fig. 1). The

post space was prepared using a post space drill (1,000-2,000 rpm speed) (DT Universal drill; Dentsply Sirona) and then completed using a dedicated drill the same size as the selected post. Post-space preparation was performed leaving an apical seal of 5 mm for all teeth. The canals were then dried with paper points.

Etching was performed with a conditioner (DeTrey Conditioner; Dentsply Sirona, Weybridge, UK) for 15 s. One to 2 drops of adhesive (Prime & Bond NT Dual-Cure; Dentsply Sirona) were mixed with an equal number of drops of self-cure activator for 2 s. The adhesive mix was applied to cavity surfaces, gently dried for 5 s with a moderate air flow, then applied to the post and air dried. Resin cement (Core-X Flow; Dental Trey, Dentsply srl) was immediately placed onto the post surface and to the orifice of the post hole preparation. Light curing was performed for 40 s at 600 mW/cm² (SmartLite Focus Pen-Style LED Curing Light; Dentsply Sirona).

Table 3 Descriptive statistics of all groups and subgroups

	n	Mean	StDev	Variance	Minimum	Q1 M	edian	Q3 Ma	ximum	Range
01	10	551.3	34.8	1211.1	496.3	507.1	563.0	572.5	596.9	100.6
02	10	422.7	36.5	1328.8	368.4	395.8	432.2	444.7	472.3	103.9
03	10	344.6	46.9	2199.4	270.2	303.6	346.0	389.7	404.1	133.9
A_1	15	696.6	31.4	988.09	657.7	674.2	681.7	725.1	758.0	100.2
A_2	15	550.4	60.2	3626.9	434.9	522.4	554.7	612.8	617.0	182.1
A_3	15	535.1	59.2	3510.4	431.9	500.1	533.1	604.3	625.2	193.4
B_1	15	463.5	51.8	2687.8	362.8	398.2	490.2	492.8	506.1	143.3
B_2	15	331.3	52.7	2780.5	280.5	290.7	306.1	382.4	437.2	156.6
B_3	15	308.3	57.2	3274.1	221.0	263.2	345.2	351.8	373.5	152.5
C_1	15	637.6	44.9	2019.3	567.1	593.2	647.8	677.4	696.0	128.9
C_2	15	555.6	67.6	4564.3	447.3	523.4	547.3	570.1	685.9	238.6
C3	15	615.4	51.4	2639.1	518.8	588.8	600.3	630.5	747.7	228.8

Table 4 Interactions among subgroups A, B, and C within the test groups 1, 2, and 3

	Differences of level	Differences of mean	95%CI	T-value	Р
Intact tooth	$A_{1} 0_{1}^{*}$	145.3	(99.6; 191.1)	8.44	< 0.001
	$B_1^* O_1^*$	-87.8	(-133.6; -42.1)	-5.10	< 0.001
	$C_{1}.0_{1}^{*}$	86.3	(40.5; 132.1)	5.01	< 0.001
	$B_1^* A_1$	-233.1	(-274.1; -192.2)	-15.14	< 0.001
	$C_1 A_1$	-59.0	(-99.9; -18.1)	-3.83	< 0.05
	$C_{1}B_{1}^{*}$	174.1	(133.2; 215.0)	11.31	< 0.001
Three residual walls	A ₂ .0 ₂	127.7	(65.9; 189.5)	5.49	< 0.001
	$B_2^* 0_2$	-91.4	(-153.2; -29.5)	-3.93	=0.001
	C2.02	132.9	(71.1; 194.8)	5.72	< 0.001
	$B_2^*A_2$	-219.1	(-274.4; -163.7)	-10.53	< 0.001
	C ₂ .A ₂	5.3	(-50.1; 60.6)	0.25	§0.994
	$C_2 \cdot B_2^*$	224.3	(169.0; 279.6)	10.78	< 0.001
Two residual walls	A ₃₋ 0 ₃	190.5	(131.3; 249.7)	8.56	< 0.001
	$B_3^*.0_3$	-36.3	(-95.5; 22.9)	-1.63	[§] 0.371
	C ₃₋ 0 ₃	270.8	(211.6; 330.0)	12.16	< 0.001
	$B_{3}^{*}A_{3}$	-226.8	(-279.7; -173.8)	-11.39	< 0.001
	C ₃₋ A ₃	80.3	(27.3; 133.2)	4.03	< 0.05
	$C_{3}B_{3}^{*}$	307.0	(254.1; 360.0)	15.42	< 0.001

No statistically significant differences detected (Tukey test for multiple comparisons). *Groups 01, B1, B2, and B3 presented non-normality of distribution but homogeneity of variance (Kruskal-Wallis test).

The mesial and distal walls (groups 2 and 3) were previously restored using a total-etch adhesive system (XP-Bond, Dentsply srl) and resin composites (Ceram-X Duo E2; Dentsply srl). Control groups were restored in the same way, but no posts were used.

All materials used for post-endodontic restoration along with their composition are listed in Table 2.

Experimental model

Teeth were embedded in self-curing resin blocks (Gnathus cold self-curing acrylic resin; Zhermak, Badia Polesine, Italy) surrounded by aluminum cylinders with the long axis perpendicular to the base of the blocks, leaving 2 mm of the roots exposed apically from the CEJ. A universal loading machine (Triaxal Tester T400 Digital; Controls Srl, Cernusco, Italy) was used. Each specimen was inserted into the holding device perpendicularly to the horizontal plane. A controlled load was applied using a stainless steel rod with a tip diameter of 2 mm. The pressure of the rod tip was applied 2 mm from the apex of the palatal cusp in the direction of the central fossa, to simulate an occlusal vertical load. The load was applied at a crosshead speed of 1 mm/min. All samples were loaded until fracture, and the maximum breaking load was recorded in Newtons (N).

After the test, specimens were observed under a stereomicroscope (SZR-10; Optika SRL, Ponetranica, Italy) at x80 to evaluate the failure pattern. Failures were highlighted using an aqueous methylene blue solution (1%) and divided into favorable (F) and unfavorable (U) according to whether or not they crossed the CEJ.

Statistical analysis

The normal distribution of data and homogeneity of variances were proved using the Shapiro-Wilk and Levene tests, respectively. ANOVA was used to detect statistical significance between 2 or more groups. When at least 1 group presented a generic distribution of data, the non-parametric Kruskal-Wallis test was used. The *post-hoc* Tukey test was applied for multiple comparisons. All statistics were performed using Minitab 19 software with the level of significance set at $\alpha = 0.05$ for all tests.

Results

Collected data are listed in Table 3. The results of interactions between the groups for "type of restoration" variable are listed in Table 4.

Statistically significant differences were observed between all test groups and the respective control groups, except between subgroup B₃ and control 0₃. Within the test groups, statistically significant differences were found between the 3 subgroups for the type of restoration (P < 0.05), except between subgroups A₂ and C₂.

For intact teeth (group 1), statistically significant differences were found among all 3 tested subgroups, the single post subgroup A_1 showing resistance values almost twice as high as oval post subgroup B_1 .

For group 2, statistically significant differences were detected between oval post and the other 2 subgroups; no differences were observed between the single and multi-post subgroups.

For group 3, statistically significant differences were found among all subgroups, in particular the oval post subgroup showed resistance values 50% lower than those for the multi-post subgroup.

Interaction analysis between groups with the same type of post-endodontic restoration but different amounts of residual dental substance was performed (Table 5). Statistically significant differences from the 3 control groups were found.

Single and oval post restorations showed the same pattern. In both cases, significant differences were observed between intact teeth and teeth with 2 and 3 residual walls, respectively, but not between teeth with loss of 1 wall and 2 walls.

For multi-post restorations, statistically significant differences were observed only between teeth with 2 residual walls and intact teeth or teeth with 3 residual walls, respectively.

The incidence of failure patterns is represented in Fig. 2.

Discussion

The aim of this study was to evaluate if the amount of residual tooth substance and type of post endodontic restoration affected the fracture strength

Table 5 "Residual dental substance" variable, within subgroups A, B, and C

	Differences of level	Differences of mean	95%CI	T-value	Р
No post (control)	02-01	-128.7	(-172.8; -84.5)	-7.24	< 0.001
	03-01	-206.7	(-250.8; -162.6)	-11.63	< 0.001
	03-02	-78.0	(-122.1; -33.9)	-4.39	< 0.001
Single post	A_2-A_1	-146.3	(-194.3; -98.3)	-8.10	< 0.001
	A_3-A_1	-161.5	(-209.5; -113.5)	-8.95	< 0.001
	A ₃ -A ₂	-15.2	(-63.2; 32.8)	-0.84	[§] 0.834
Oval post	$B_2^* - B_1^*$	-132.2	(-182.0; -82.4)	-7.05	< 0.001
	$B_{3}^{*}-B_{1}^{*}$	-155.2	(-205.0; -105.3)	-8.28	< 0.001
	$B_{3}^{*}-B_{2}^{*}$	-23.0	(-72.8; 26.9)	-1.22	[§] 0.614
Multi-post	C ₂ -C ₁	-82.0	(-134.5; -29.6)	-4.16	< 0.05
	C ₃ -C ₁	-22.2	(-74.7; 30.2)	-1.13	[§] 0.675
	C3-C2	59.8	(7.3; 112.2)	3.03	< 0.05

⁸No statistically significant differences detected (Tukey test for multiple comparisons). *Groups 01, B1, B2, and B3 presented non-normality of distribution but homogeneity of variance (Kruskal-Wallis test)

Incidence of fracture patterns



Fig. 2 Percentage incidence of favorable (%) and unfavorable (%) fractures

of endodontically treated maxillary premolars. The results indicated that both variables influenced the fracture strength values. The null hypothesis tested was therefore rejected. It has been widely recommended that post placement should be performed without sacrificing radicular dentin [14]. Post space preparation could compromise existing tooth structure [15] and increase tooth loss risk due to radicular cracks [16]. Therefore, this study employed a minimally invasive protocol, and posts of the smallest available diameter were chosen.

The multi-post technique performed significantly better than the single post approach when both marginal ridges were missing. This is in accordance with a study by Sorensen et al. [17], showing that the fracture resistance of ETT increased when posts were adapted tightly to canal walls. The use of small-diameter posts with the multi-post technique enables practitioners to fill large and irregular root canals more efficiently than with a single centrally positioned post [18]. For intact teeth, single post restoration yielded the best results, perhaps because this placement procedure allowed for a more extensive preservation of dentin structure. In fact, all procedures leading to appreciable removal of inner dentin during post-preparation may considerably weaken the root. Irrespective of the type of post-endodontic restoration, fracture resistance decreased as the amount of coronal residual dental substance was reduced, as observed in a previous study [19]. The single-post and multi-post techniques showed a significant higher fracture resistance than direct restorations without any intra-radicular retention. This may be because premolars are subjected to more fracture risk [7,8]; consequently, restoring an ETT with a post distributes stress more evenly, thus increasing fracture resistance [20]. Sorrentino [10] and Salameh [3] demonstrated that the presence of a post did not increase the strength of teeth that have lost less than 1 wall.

The oval post, on the other hand, demonstrated no improvement in restoration strength, perhaps because of the apical grooves on the post itself interfering with adhesion. This is in accordance with a previous study showing that an oval fiber post did not improve adaptation to ovalshaped canal walls [21] or the fracture resistance of ETT [22]. However, previous results have been conflicting [23], possibly due to differences in methodology between studies (e.g. sample preparation parameters, testing parameters).

The insertion of an intra-radicular retention increased the incidence of favorable fractures, as shown in previous studies [5,10]. In control groups where no post system was placed, the incidence of irreversible failure was 80% and it decreased progressively when restoration was done using the single, oval or multi-post techniques. On the other hand, the incidence of favorable fractures increased as the coronal residual walls were reduced. In fact, when intensive dental substance loss occurs, stresses will concentrate in the cervical region and cause favorable failure patterns; however, as the remaining coronal walls increase, stresses will be increasingly transmitted to the apical area, causing irreparable failures.

The present *in vitro* study had some limitations, one of which was the standardization of the restorative procedures, which could have altered root canal morphology. An ideal study design would have employed teeth with a very similar three-dimensional root canal anatomy and root dentin thickness. However, due to the wide anatomical variability of human premolars [23], the standardization process was necessary to allow comparability.

Premolars are subject to lateral forces much more frequently than molars. Most studies of fractures have used premolars loaded on the palatal cusp with an inclination of 30-45° [23] to the longitudinal axis of the tooth: this configuration generates a perpendicular compressive load on the inclined plane of the cusp. Conversely, during oral function, the occlusion generates extra-axial forces that are decomposed into vectors according to the parallelogram law. This is why the physiological occlusion was simulated by applying an experimental load parallel to the longitudinal axis of the tooth. All samples were subjected to fracture testing using a cylindrical plunger. The use of a spherical plunger was excluded as it would have touched the tooth surface only, and not the restorations, during loading. Experimental conditions may also have affected the overall fracture resistance of teeth [24]. Moreover, it was decided not to perform thermocycling as it has been reported that this weakens the adhesive interface, thus affecting fracture resistance [24-26]. Although a compressive load test is important when investigating the performances of restorations under certain circumstances, the static single load is just one aspect of what actually occurs in the mouth. Further studies simulating clinical conditions, such as tension tests, dynamic load application and long-term clinical trials, will be necessary to fully evaluate the performance of post-endodontic restorations.

Within the limits of this study, it can be concluded that the loss of the two marginal ridges significantly reduced the fracture resistance of endodontically treated maxillary premolars, and that the use of an intraradicular retention significantly increased their fracture strength. In oval canals the use of a single post or a multi-post improved the post-and-core restoration resistance even in intact teeth. Oval fiber posts did not improve the fracture resistance of endodontically treated maxillary premolars. A multi-post design improved fracture resistance mostly in maxillary premolars with the loss of both marginal ridges. The placement of a post system increased the incidence of favorable failures irrespective of whether the fracture strengths of endodontically treated maxillary premolars increased or decreased. Therefore, the present study has provided some practical indications: in oval canals fracture resistance was increased only by the single or multi-post techniques, and not with oval posts; a multi-post approach was found useful when both marginal ridges were lost; placement of a post system increased the incidence of favorable failures irrespective of any increase/decrease in fracture strength values.

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Conflict of interest

The authors have no conflict of interest to declare in relation to this study.

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