－ ORIGINAL ARTICLE －

Effect of post type and loading condition on the failure resistance and primary failure mode of flared canal teeth restored with fiber-reinforced or cast posts

Farhana Sharmin[1)], Roxana Stegaroiu[2)], Naoto Okada[3)], Eriko Kitamura[3)], Kouichi Kurokawa[2)], Minoru Yagi[2)], Shuichi Nomura[4)].

[1)] *Division of Oral Health in Aging and Fixed Prosthodontics, Niigata University Graduate School of Medical and Dental Sciences*
[2)] *Master's Program of Oral Health and Welfare Science, Niigata University Graduate School of Medical and Dental Sciences*
[3)] *Division of Bio-Prosthodontics, Niigata University Graduate School of Medical and Dental Sciences*
[4)] *Division of Comprehensive Prosthodontics, Niigata University Graduate School of Medical and Dental Sciences*

ファイバーポストおよび鋳造ポストで修復した歯根の種類と荷重条件が破損強さと初期破損様式に及ぼす影響

Farhana Sharmin [1)], Roxana Stegaroiu [2)], 岡田直人 [3)], 北村絵里子 [3)],
黒川孝一 [2)], 八木　稔 [2)], 野村修一 [4)]

[1)] 新潟大学大学院医歯学総合研究科　口腔生命科学専攻　口腔健康科学講座　加齢歯科補綴学分野
[2)] 新潟大学大学院医歯学総合研究科　口腔生命福祉学専攻
[3)] 新潟大学大学院医歯学総合研究科　口腔生命科学専攻　口腔健康科学講座　生体歯科補綴学分野
[4)] 新潟大学大学院医歯学総合研究科　口腔生命科学専攻　顎顔面再建学講座　包括歯科補綴学分野

平成 20 年 12 月 17 日受付　　平成 21 年 3 月 9 日受理

Key Words : cast post-and-core, failure mode, failure resistance, fiber-reinforced post, flared canal

Abstract

Objectives : This study investigated the influence of post type and loading condition on the failure resistance and primary failure mode of flared canal roots.

Materials and methods : Flared post holes were prepared in 40 sound human lower premolar roots. Twenty roots received glass fiber posts with resin core (fiber specimens) and 20 received cast post-and-core (cast specimens). After cementation with resin cement, in 10 fiber and 10 cast specimens, a quasi-static bending test was performed by an Instron-type testing machine. In the other specimens, before the bending test, a bucco-lingual load was applied for 900,000 cycles using a lever-type device. Failure resistance and primary failure mode in relation with post type and loading condition were statistically analyzed (significance level: 0.05).

Results : After cyclic loading, all specimens were intact; therefore, they underwent the bending test. Failure resistance showed a significant difference only for the post type ($p = 0.002$) (two-way ANOVA). In the presence of cyclic loading, the post type significantly influenced failure resistance ($p = 0.010$), whereas in its absence, it showed only a tendency to influence failure resistance ($p = 0.054$) (Tukey test). In the cycled specimens, significantly fewer root fractures and more frequent debonding without root fracture were found in the fiber than in the cast specimens ($p = 0.02$) (Fisher's exact test).

Conclusions : Rather than cast post-and-cores, the use of glass fiber-reinforced posts and resin core for the restoration of flared canal teeth may prevent root fracture, but debonding may occur under high loads.

抄録：本研究は漏斗状に窩洞形成された歯根の修復物における破損強さと初期の破損様式に、ポストの種類と荷重条件が及ぼす影響を検討した。

漏斗状に根管形成した抜去下顎小臼歯40歯を用い、20歯にはガラスファイバーポストとコンポジットレジンコア（ファイバーポスト群）、残りの20歯には鋳造ポストと鋳造コア（鋳造ポスト群）で支台築造を作製し、レジンセメントで被験歯に合着した。各ポスト群10歯に、インストロン型万能試験機を用いてポスト－歯根複合体が破損するまで準静的曲げ試験を行った。残りの被験歯には、曲げ試験の前に、てこ型試験機を用いて2-kgfの頬舌的荷重を90万回加えた。反復荷重では全ての試料が破損しなかったので、引き続き準静的曲げ試験を行った。

破損強さの測定値には二元配置分散分析法で、ポストの種類に有意差が認められた（p = 0.002）ものの、荷重条件要因および二要因間の交互作用には有意差が認められなかった。Tukey法の多重比較検定結果から、ポストの種類は反復荷重があると破損強さに有意差を示した（p = 0.010）が、反復荷重がないと影響する傾向を示したものの有意には達しなかった（p = 0.054）。破損様式に関しては、反復荷重を行った試料ではFisher'sの直接確率計算法で分析すると、ファイバーポスト群が鋳造ポスト群よりも有意に歯根破折が少なく、歯根破折を伴わないポスト脱離が多かった（p = 0.020）。90万回作用させた疲労試験とそれに続く準静的曲げ試験の結果から、漏斗状に窩洞形成された歯根の修復物には、鋳造ポストよりもガラスファイバーポストとコア築成材料を用いる方が歯根破折を防ぐ可能性が示された。しかし、このガラスファイバーポストを用いた修復物には、大きな頬舌的荷重が作用すると偶発症として、ポスト脱離が高頻度に生じる可能性がある。

1. Introduction

Although many studies have pointed out the importance of preserving sound tooth structure apical to the dowel-core margin, so that the crown can brace the endodontically treated teeth and prevent fracture ("ferrule effect"),[1-4] clinicians are often faced with the need of restoring teeth with extensive caries, in which no ferrule can be maintained and the remaining dental structure is rather fragile. For this purpose, custom cast post-and-core buildups or prefabricated metallic posts with resin cores have been traditionally used, but a series of shortcomings has become evident in time. A serious complication that often leads to tooth extraction is root fracture.[2,5] *In vitro* investigations of different post systems have found that teeth restored with cast or prefabricated metallic posts demonstrated most catastrophic failures by root fractures.[6-8] Esthetic complications[9] and allergic reaction to metal[10] have been also related to metallic posts. Therefore, non-metallic posts have been added to the treatment options of endodontically treated teeth. Among these, glass fiber-reinforced posts are esthetic and, according to the manufacturer, their modulus of elasticity is 29.2 GPa, which is much closer to that of dentin (14.2 GPa[11]) than dental alloys (90-100 GPa[12,13]). Recently, the use of post materials with physical properties close to those of natural dentin has been recommended[4]. These are expected to decrease the stress in the dental structure, and thus reduce the incidence of catastrophic root fracture. Although this supposition is supported by studies using only structurally sound roots,[6,8] the clinical use of glass fiber-reinforced posts has been also extrapolated to restore structurally compromised teeth whose post-hole preparation end up in flared canals. These are at higher risk for fractures than the sound roots, because of the thin walls remaining[14]; however, whether the selection of post type can improve the failure resistance of roots with flared canals has yet to be determined.

Clinical failures in fixed prosthodontics are often caused by fatigue, as a result of long periods of function under occlusal forces (mastication, swallowing, etc.); fatigue failures of the tooth-restoration complex have been clinically reported in connection with endodontically treated teeth restored with posts and cores[15]. However, when applications of new materials or techniques are tested *in vitro*, failure resistance of teeth restored with posts and cores are investigated by quasi-static rather than fatigue tests.[6-8, 14, 16-18] Among the few studies that used fatigue loading to compare fracture strength of fiber and metallic posts, one evaluated their torsion resistance[19], while another study used high-stress cyclic loading in wet conditions[20]. These studies bring valuable insight into the fatigue failure of structurally sound roots restored with different posts. However, clinically, rather than being exposed to torsion, teeth are compressed and bent by the axial and lateral components of the occlusal load, respectively. Thus, the effects of these components and especially that of the lateral component, which has a higher potential of damaging teeth, have to be also investigated. Moreover, although testing under high-stress loading is time-efficient, applying loads that are in the physiological range for a high number of cycles will more closely simulate the intraoral biomechanical environment that may finally lead to fatigue failure. Regarding the number of cycles, Wiskott et al[21] consider fatigue tests as conclusive for clinical restorations if they are conducted up to a range of 10^4 - 10^7 cycles.

Furthermore, in both static and fatigue studies on failure of post-restored teeth, the outcome parameter has been in many instances fracture strength/resistance.[18,19] However, beside root/post fractures, clinical failures of teeth restored with posts and cores have also included loss of retention and marginal gaps.[22, 23] Thus, the present study was designed to record the first sign of failure (primary failure[17]): fracture of the tooth-restoration complex, debonding (loss of post retention or presence of marginal gaps), etc. Its purpose was to investigate the influence of post type and loading condition (presence or absence of a 2-kgf (19.62 N) lateral load that was applied in 9 x 10^5 cycles), on the failure resistance and primary failure mode of roots with flared canals restored with posts and cores. Two hypotheses were tested: 1) Post type influences failure resistance and primary failure mode of flared roots restored with a fiber-reinforced post and composite core or cast post-and-core and 2) the loading condition influences the failure resistance and primary failure mode of flared roots restored with the abovementioned posts and cores.

2. Materials and methods

2.1 Teeth preparation

Freshly extracted mandibular premolars were disinfected with 6% sodium hypochlorite solution (Purelox, OYALOX Co., Ltd., Tokyo, Japan) and inspected under a stereomicroscope to check for caries, crack and stain. Forty intact teeth of similar dimensions were selected and stored in isotonic saline solution. The mean dimensions (SD) of the teeth as measured at the most apical level of the cementoenamel junction were: 4.95 (0.43) mm mesiodistally, 7.25 (0.64) mm buccolingually, and 13.96 (1.32) mm in root length.

Each tooth was decoronated with a diamond point at the most apical level of the cementoenamel junction and the root section was flattened by a carborundum disk to obtain a surface perpendicular to the longitudinal tooth axis.

All teeth were endodontically instrumented up to a size 50 K-type file (MANI Inc., Ustunomiya, Tochigi, Japan) with water irrigation between file sizes. After the canals were dried, they were obturated using the lateral condensation technique, with gutta-percha master points #50 (GC Co. Tokyo, Japan), auxiliary cones (GC Co.) and a calcium hydroxide root canal sealer (Sealapex, Kerr Manufacturing Co., Romulus, MI, USA). A small quantity of zinc phosphate cement (Shofu Inc, Kyoto, Japan) was filled on top of the gutta-percha and the specimens were stored in the saline for at least 7 days before canal preparation.

The canals were prepared to receive posts (Fig 1) to a depth of 8 mm with #1 through #3 Peeso reamers (MANI Inc., Ustunomiya, Tochigi, Japan) and #1 through #2 tapered reamers (RTP Reamer, Dentech, Tokyo, Japan). On the lingual aspect, a keyway type antirotational groove was also prepared with a diamond bur. Thereafter, the canal was flared in the cervical area by a conical carborundum point, to simulate the preparation required in gross carious destruction (Fig 1). In all the specimens, the mesiodistal width of the remaining tooth structure in the cervical area was 1 mm on each side.

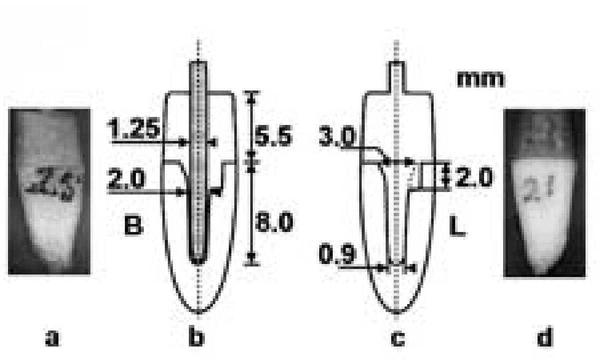

Fig 1. Photographs of specimens before mechanical testing and schematic diagrams of root canal preparation and post & core design (dimensions in mm): a and b, with glass fiber-reinforced composite resin post and glass fiber-reinforced core build-up material; c and d, with cast post-and-core. (B = buccal, L = lingual).

2.2 Post and core fabrication and cementation

All the posts were fabricated by the indirect method. The impressions were taken with putty and injection types of vinyl polysiloxane impression material

(Imprinsis, Tokuyama Dental Co., Tokyo, Japan). From these impressions, stone dies (Fuji rock, GC Co., Tokyo, Japan) were fabricated. In half of the specimens, the dowel was fabricated from glass fiber-reinforced composite resin posts (FibreKor, Jeneric/Pentron Inc., Wallingford, CT, USA) and glass fiber-reinforced core build-up material (Build-It, Jeneric/Pentron Inc., Wallingford, CT, USA), to morphologically fit the tooth preparation. The same build-up material was used for the core. In all the specimens, core build-up caps for premolars (Build-it! Core Forms size 3, Jeneric/Pentron Inc., Wallingford, CT, USA) were used to standardize core dimensions. In the remaining specimens, wax patterns were shaped on the stone dies and a 10-mm long sprue was positioned on the top of the core as to be aligned to the post axis. After investing and wax burnout, the mold was cast with a dental alloy (Castwell M.C., GC Co., Tokyo, Japan) that consisted primarily of 46% Ag, 20% Pd, 20% Cu, and 12% Au.

Before cementation, all posts were cleaned with an alcohol wipe, air-particle abraded with a 50 μm aluminum oxide abrasive powder and a bonding agent (Bond one, Jeneric/Pentron Inc., Wallingford, CT, USA) was applied in one coat on the surfaces to be cemented and dried gently. In addition in the cast specimens, an alloy primer (Alloy primer, Kuraray Medical Inc., Tokyo, Japan) was applied before the bonding agent. In all the specimens, the dentin surfaces to be cemented were etched with phosphoric acid etching agent (K-etchant Gel, Kuraray Medical Inc., Tokyo, Japan) for 20 s and then thoroughly rinsed. Following manufacturer instructions, the excessive moisture was removed, but the surface was left moist. Then, the same bonding agent was applied in 2 consecutive coats and the dentin surfaces were gently dried for 10 s, before light-curing for 10 s. Cementation was performed with resin cement (Universal C&B: Cement-It, Jeneric/Pentron Inc., Wallingford, CT, USA), following manufacturer's instructions.

After cementation and between the experimental steps that followed, each tooth was kept in saturated humidity at 37℃, using a hotting bath (Magnetic stirrer, TOYO Chemical Laboratories Inc, Tokyo, Japan). Twenty-four hours after cementation, the following technique was designed in an attempt to simulate tooth physiological mobility: the portion of the root to be embedded was covered with one layer of Scotch tape and each root with restoration in place was fixed in the central hole of a resin block with an orthodontic resin applied in layers (Dentsply International Inc., York, PA, USA) up to 2 mm below the root surface level. To ensure the bond to both root and resin, a cyanon adhesive (Dental cyanon, Koatsu Gas Kogyou Co., Ltd., Chiba, Japan) was used on the inner side of the Scotch tape during taping and on its outside with each of the orthodontic resin layers. During this procedure, the preserved sprue of the cast core or the top of the fiber post was fixed in the arm of a surveyor, to align the post to the vertical axis. Prior to the cyclic loading, the artificial mobility of the restored teeth was evaluated by measuring the buccolingual deflection of the loading point with an electric micrometer (Minicom, Tokyo Seimitsu Co., LTD., Tokyo, Japan) in the same setting as for the mechanical tests. Under 2 kgf (19.62N) load, the mean (∓ SD) was 35.7 (∓ 21.6) μm.

2.3 Fatigue loading

Half of the cast and half of the fiber specimens were firmly mounted in a brass holder of a custom-made lever-type fatigue testing machine.[24] Serrate-type cyclic loading between 0 and 2 kgf (19.62N) was applied to the buccal face of the core, 4 mm from the cemento-enamel junction (Fig. 2). The load was applied at a rate of 80 cycles/min (1.33 cycles/s) for 900,000 cycles in a wet environment at room temperature. During each cycle the specimens were loaded for 0.3 s. The machine was equipped with 2 types of shutoff sensors to automatically discontinue loading in case of specimen failure.

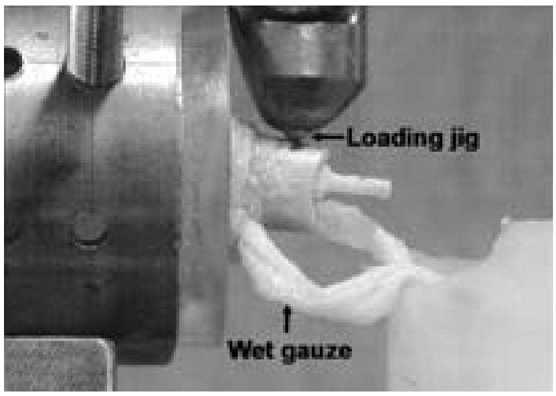

Fig 2. Fiber specimen mounted in the brass holder of a lever-type fatigue testing machine. The wet environment during the cyclic loading was created by wet gauze, which emerged from a recipient filled with water and encircled the cervical portion of the root.

2.4 Bending test

In the specimens, in which no failure occurred after the cyclic loading, and in those that did not underwent cyclic loading, a single-cantilever bending test was performed. The specimens were secured in an Instron-type testing machine (AG-1000E, Shimadzu, Kyoto, Japan) and an increasing load (crosshead speed of 1 mm/min) with the same direction and location as in the mechanical cycling was applied until failure was recorded. For each specimen, the magnitude of the force causing failure was recorded in kgf.

The primary failure mode was defined from both the force-deflection curve and specimen appearance at the in-situ visual inspection. While it was recorded, the force-deflection curve was continuously watched; when a small, gradual drop-down in the force curve occurred, the sample was visually inspected for gaps between core and root. When any gap became visible, the machine was stopped to avoid further destruction. Then, the roots were cut out of the embedment resin and the specimens were inspected by a stereomicroscope to check for any other damage of the tooth or restoration. The presence of a gap between core and root without any fracture of the dental structure was defined as "debonding". Conversely, when no gradual drop occurred in the force-deflection curve and no gap was visible, the force was increased almost linearly until a considerable, sharp drop-down could be depicted. At that point, the testing machine was immediately stopped and the specimens were inspected, as described above. In these specimens, root fracture was always detected and the primary failure mode was defined as "root fracture".

2.5 Statistical analysis

The failure resistance (load-to failure) data were analyzed statistically by two-way ANOVA (2 x 2) and an all pairwise multiple comparison procedure (Tukey Test) ($p < 0.05$), after the normal and homogeneous distribution of the data was confirmed.

Specimen mode of failure was classified as either debonding (without root fracture) or root fracture. The frequencies of root fracture occurrence in each group were counted and compared by Fisher's exact probability tests, to determine the probability of an association between post type and occurrence of root fracture in each loading condition, as well as that between loading condition and occurrence of root fracture in each post type. The statistical analyses were performed using a commercial computer program (SigmaStat 2.03, SPSS, Chicago, IL, USA).

3. Results

In the cycled specimens, no failure was recorded at the end of the test; therefore, all the specimens were then subjected to the quasi-static bending test in the Instron-type testing machine.

3.1 Failure resistance

Since the failure resistance data showed normal and homogeneous distribution, they were analyzed by two-way ANOVA (2 x 2) (Table 1), which showed a statistically significant difference for the factor post type ($p < 0.05$). However, no statistically significant difference was detected for the factor load condition, or for the interaction between the 2 factors ($p > 0.05$). The mean failure resistance and standard errors of the means for each group are illustrated graphically in Fig 3. The Tukey test showed that, in the presence of cyclic loading, the post type resulted in a statistically significant difference ($p < 0.05$) (Table 2), with higher resistance of the cast specimens. In the absence of cyclic loading, post type showed a tendency to influence failure resistance, but without reaching significant difference ($p = 0.054$). Loading condition

Table 1 Results of the two-way ANOVA (2 x 2) of the failure resistance values (kgf)

Source of Variation	DF	SS	MS	F	P
Post type	1	1056.578	1056.578	11.186	0.002
Load condition	1	5.837	5.837	0.0618	0.805
Post type x Load condition	1	25.536	25.536	0.270	0.606
Residual	36	3400.518	94.459		
Total	39	4488.470	115.089		

DF = degree of freedom, SS = sum of squares, MS = mean squares, F = variance ratio,
P = probability

Table 2 Results of all the pairwise multiple comparisons of failure resistance values (kgf) (Tukey Test)

Comparison for	Within	Diff of Means	p	q	P	P<0.05
Load condition	Fiber	0.834	2	0.271	0.849	No
(Non-Cycled vs. Cycled)	Cast	2.362	2	0.769	0.590	No
Post type	Cycled	11.877	2	3.864	0.010	Yes
(Fiber vs. Cast)	Non-Cycled	8.681	2	2.825	0.054	No

Diff of Means = Difference of Means, p = number of means spanned in the comparison, q = statistical datum derived in Tukey Test, P = probability

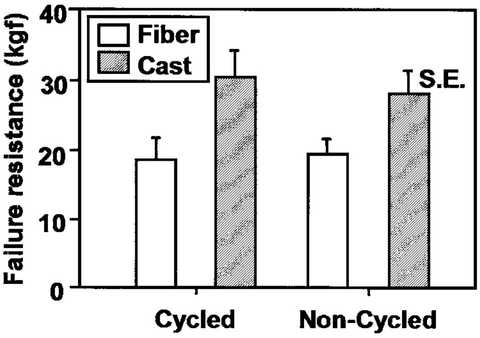

Fig 3. Bar chart of the mean failure resistance values and standard error of the mean (SEM) for each group (kgf): fiber specimens (Fiber) submitted to cyclic loading (Cycled), cast specimens (Cast) submitted to cyclic loading, fiber specimens not submitted to cyclic loading (Non-Cycled), and cast specimens not submitted to cyclic loading.

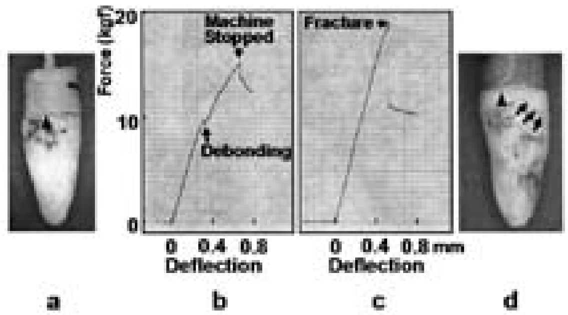

Fig 4. Stereoscopic aspects and force-deflection curves of failed specimens: a and b, fiber specimen failed by debonding (*arrow head*); c and d, cast specimen failed by root fracture (*arrows*). A slight gap of short span (*arrow head*) is also visible at the tooth-core interface.

within both fiber and cast specimens did not significantly influence the failure resistance ($p > 0.05$).

3.2 Primary failure mode

The aspect of the force-deflection curves (Fig 4b and c), in combination with the visual and stereoscopic inspection of the failed specimens (Fig 4a and d), revealed the following modes of failure: debonding of the post and core (13 specimens) and root fracture (27 specimens). In 22 of the root-fractured specimens, an oblique fracture line was visible in the cervical quarter of the root. This crack started at the cervical surface of the root on one proximal aspect and descended towards the lingual aspect, on which its most apical level was observed about 1 mm beneath the embedment resin surface. In many specimens, the crack then rose on the opposite proximal aspect towards the cervical surface of the root where it ended. In the other post-fractured specimens, 3 vertical root fractures and 2 apical root fractures were recorded. Furthermore, in 10 of the root-fractured specimens (5 cycled cast, 2 cycled fiber, and 3 non-cycled cast specimens) slight gaps were also observed microscopically at the core-dentin interface.

Table 3 shows the results of the Fisher's exact probability tests, in which the probability of an association between post type and occurrence of root fracture was analyzed for the cycled and non-cycled specimens, respectively. In the cycled specimens, significantly fewer root fractures were found in the fiber specimens than in the cast specimens ($p < 0.05$). However, no significant difference was found in the non-cycled specimens ($p > 0.05$). Table 4 shows the Fisher's exact probability tests, in which the probability of an association between loading condition and occurrence of root fracture was analyzed for the fiber and cast specimens, respectively. In the fiber specimens, although a tendency of less root fractures was found in the presence than in the absence of cyclic loading, this difference did not reach significance ($p = 0.179$). In the cast specimens, no significant difference was found in association with loading condition ($p > 0.05$).

4. Discussion

To have clinical relevance, an *in vitro* test should simulate intraoral conditions as accurately as possible. In this respect in the present study, the independent

Table 3 Comparison of the primary mode of failure (occurrence/ non-occurrence of root fracture) between the cycled fiber and cast specimens, as well as between the non-cycled fiber and cast specimens (Fisher's exact probability tests)

Load condition	Post type	Root fracture	No fracture but debonding	P value
Cycled	Fiber	3	7	0.020
	Cast	9	1	
Non-Cycled	Fiber	7	3	1
	Cast	8	2	

Table 4 Comparison of the mode of failure (occurrence/non-occurrence of root fracture) between the cycled and non-cycled fiber specimens, as well as between cycled and non-cycled cast specimens (Fisher's exact probability tests)

Post type	Load condition	Root fracture	No fracture but debonding	P value
Fiber	Cycled	3	7	0.179
	Non-Cycled	7	3	
Cast	Cycled	9	1	1
	Non-Cycled	8	2	

variables that may remarkably influence the outcome were set as close as possible to those of the intraoral environment. Since dryness makes teeth more brittle, each specimen was kept wet during both storage and the approximately 9-day long fatigue test.

To simulate the biomechanical behavior of tooth during function, applied load and tooth constraints are important. Graf & Grassl[25] have reported that lateral force peaks between 0.5 and 2 kgf were observed in the buccal direction of the molar teeth; during the fatigue test of this study, the tooth was slightly challenged by setting the load to the upper value (2 kgf). During each cycle, the specimens were loaded for 0.3 s, which approximately corresponds to the duration of tooth contact in one chewing cycle.[26-28] The cyclic loading was carried out at 80 strokes/min, which is within the range of the average human chewing frequency (70 to 80 cycles/min).[26,27] The duration of cyclic loading (900,000 strokes) may be equivalent to 3 years of clinical function, because it has been estimated that application of fatigue-type stress during mastication may amount to approximately 300,000 flexures per year.[12,26]

Regarding tooth constraints, a too rigid constraint of the root during the mechanical testing will lead to a more stressful biomechanical environment than the intraoral fixation of the tooth in the alveolar socket, whereas a too loose constraint will have an opposite effect. To ensure artificial tooth mobility similar to the physiological behavior, one layer of Scotch tape was wrapped and bonded around each root, before fixation in orthodontic resin. This resulted in a mean buccolingual deflection (SD) of 35.7 (21.6 μm), which is within the physiological range (17 - 39 μm) reported for the same load direction and a similar location in the dental arch.[29]

The statistic analysis of the failure resistance data by ANOVA (Table 1) showed that post type influenced the failure resistance of flared roots restored with a fiber-reinforced post and composite core or cast post-and-core. Moreover, the Tukey test (Tables 1 and 2) showed a significant difference for the post type in association with cyclic loading, with lower failure resistance in the fiber than the cast specimens (Fig. 3). Although the factor loading condition was not found to significantly influence the failure resistance (Table 2), it showed a tendency of affecting the failure mode in the fiber specimens (Table 4). Putting all these facts together the following explanation could be given. Fatigue loading in wet environment, in association with the use of composite resin added cervically around the fiber-reinforced post to fit the flared canal, increased the likelihood of debonding in the fiber specimens. This supposition is supported by the fact that significantly more failures by debonding without root fracture were found in the fiber than the cast specimens in the presence, but not in the absence of cyclic loading (Table 3). Another argument in favor of this explanation is that, in the fiber specimens, a tendency of more debonding without root fracture was found in the presence than in the absence of cyclic loading; however, this was not the case for the cast specimens (Table 4), in which instead of composite resin, a dental alloy that is more resistant to cyclic loading and humidity ensured the post fit into the flared canal. In the fiber specimens, the adhesive resin cement, matrix resin of post, and composite resin might have been deteriorated by the fatigue test in the wet environment and this may have allowed for a greater deflection and thus a larger deformation of the more flexible fiber-reinforced post. This put a higher burden on the weakest tooth-adhesive cement-composite resin interfaces, which therefore failed at lower loads than the weakest link of the tooth-restoration complex in the cast specimens. In contrast, the more frequently encountered root fracture and resistance to higher loads in the cycled cast specimens can be explained by the higher stiffness of these posts, as compared with the glass-fiber reinforced posts and the cervically added composite resin. Higher loads were needed to deflect them, and thus a higher burden was concentrated in the cervical region of the surrounding tooth structure. This ended up in more root fractures. Once a fracture occurred, a higher burden was transferred to the tooth-cement interface and slight debonding (gaps) followed immediately in half of the cycled cast specimens. On the other hand in the absence of cyclic loading, the difference in stiffness of the 2 posts could explain the tendency of higher failure resistance in the cast than the fiber specimens; however, in the absence of the fatigue test in wet environment, the tendency did not reach significance (Fig 3).

In the present study, root fractures and debonding (gaps at the core-dentin interface) were recorded as modes of failure. The later were most probably caused by the debonding at the post-dentin interface. Clinically, the following mechanical failures have been reported in teeth restored with posts and cores: root or restoration fracture, restoration loss of retention, marginal gaps, etc.[22,23,30-32] Among these, root fractures and debonding of the post and core (post loosening) have been reportedly the most common post and core complications clinically encountered.[32] Thus, it may be extrapolated that in a mechanical test, rather than recording only the specimen fracture, the investigation of the initial sign of failure may lead to an outcome of clinical relevance.

This study is also in agreement with *in vitro* studies on fiber posts, in which significantly higher failure loads, but more tooth fractures, were reported for cast post-and-core specimens in comparison with carbon-fiber post specimens[18] or glass fiber-reinforced posts when tested without crown coverage.[8] In another study that investigated failure resistance and primary failure mode of post-and-core submitted to quasi-static compressive load, a tendency of increased failure resistance, but no significant difference, was reported for teeth restored with cast post-and-cores in comparison with those restored with carbon-fiber posts.[17] Although the difference in the direction of force application does not allow for direct comparison, the findings of the abovementioned study are in agreement with the results of the cast and fiber specimens not subjected to cyclic loading in the present study.

From the point of view of re-treatment options, *in vitro* studies on the failure resistance/mode of post-and-core restored teeth often classify modes of failure into "favorable /unfavorable"[17] or "retrievable/irretrievable",[8] while clinical studies similarly define "reversible/irreversible" complications.[33] Similarly, the failure modes recorded in the present study could be classified as either "favorable" ("reversible") or "unfavorable" ("irreversible"). Debonding without fracture fell in the first category, since re-cementation of the restoration could be a possible re-treatment option, while root fracture was classified into the latter, because the fracture line continued well below the simulated bone level, and thus would most probably imply tooth extraction. From this point of view, the use of glass-fiber reinforced posts, which led to significantly less root fractures after cyclic loading, may prevent root fracture to a greater extent than cast post-and-cores, but debonding, a reversible complication, may occur under high buccolingual load. However, an 18-year retrospective survival study that included full crowns with posts warns that the occurrence of a previously reversible complication is a predicting factor for an irreversible complication.[33] Therefore, any complication should be carefully analyzed and its cause should be removed, to avoid a more serious complication that can end up with tooth extraction.

Finally, some limitations of this study needs to be acknowledged. A study that compared failure resistance/modes of various post systems at different stages of tooth restoration showed different results for teeth restored with post-and-cores only and those additionally covered by crowns.[8] This implies the necessity of further testing of post-and-cores under crown coverage to increase clinical relevance of the results. Moreover in the present study, cyclic loading tended to influence failure mode in the fiber specimens only, and it did not significantly affect failure resistance. Prolonged cyclic loading needs to be performed to elucidate the effect of loading condition on the failure resistance/mode of restored teeth.

5. Conclusions

Within the limitations of this *in vitro* study, the following conclusions were made:

1) Rather than cast post-and-cores, the use of glass-fiber reinforced posts and core build-up material for the restoration of flared canal teeth may prevent root fracture, as found in a fatigue test followed by a quasi-static bending test. However, debonding, a reversible complication, may more frequently occur in these fiber-post teeth under high buccolingual loads.
2) After 900,000 load cycles, flared canal teeth restored with cast post-and-core resisted to significantly higher loads than those restored with fiber posts, but when they failed, significantly more unfavorable failures (root fractures) were recorded.
3) The application of 900,000 cycles of load tended to influence primary failure mode in the fiber specimens only, and it did not significantly affect failure resistance. Prolonged cyclic loading needs to be performed to elucidate the effect of loading condition on the failure resistance/mode of restored teeth.

Acknowledgements

This study was supported in part by a Grant for Promotion of Niigata University Research. We express our gratitude to Prof. Emeritus Osamu Miyakawa, Niigata University for his invaluable guidance throughout the study. We are also grateful to Mr. Syuji Nakano for technical assistance. We also thank Pentron Japan Inc. for providing the resin cement and bonding agent.

References

1) Shillingburg HT, Jr, Hobo S, Whitsett LD, Jacobi R and Brackett SE: Fundamentals of Fixed Prosthodontics. 3rd ed, p 181-209, Quintessence, Chicago, 1997.
2) Creugers NH, Mentink AG, Fokkinga WA and Kreulen CM: Five-year follow-up of a prospective clinical study on various types of core restorations. Int J Prosthodont, 18: 34-39, 2005.
3) Tan PL, Aquilino SA, Gratton DG., Stanford CM, Tan SC, Johnson WT and Dawson D: *In vitro* fracture resistance of endodontically treated central incisors with varying ferrule heights and configurations. J Prosthet Dent, 93: 331-336, 2005.
4) Dietschi D, Duc O, Krejci I and Sadan A: Biomechanical considerations for the restoration of endodontically treated teeth: A systematic review of the literature - Part 1. Composition and micro- and macrostructure alterations. Quintessence Int, 38: 733-743, 2007.
5) Morgano SM and Milot P: Clinical success of cast metal posts and cores. J Prosthet Dent, 70: 11-16, 1993.
6) Akkayan B and Gulmez T: Resistance to fracture of endodontically treated teeth restored with different post systems. J Prosthet Dent, 87: 431-437, 2002.
7) Sirimai S, Riis DN and Morgano SM: An *in vitro* study of the fracture resistance and the incidence of vertical root fracture of pulpless teeth restored with six post-and-core systems. J Prosthet Dent, 81: 262-269, 1999.
8) Cormier CJ, Burns DR and Moon P: *In vitro* comparison of the fracture resistance and failure mode of fiber, ceramic, and conventional post systems at various stages of restoration. J Prosthodont, 10: 26-36, 2001.
9) Rosentritt M, Sikora M, Behr M and Handel G: *In vitro* fracture resistance and marginal adaptation of metallic and tooth-colored post systems. J Oral Rehabil 31: 675-681, 2004.
10) Al-Hiyasat AS, Bashabsheh OM and Darmani H: An investigation of the cytotoxic effects of dental casting alloys. Int J Prosthodont, 6: 597-601, 2003.
11) Stanford JW, Weigel KV, Paffenberg GC and Sweeney WT: Compressive properties of hard tooth tissues and some restorative materials. J Am Dent Assoc, 60: 746-756, 1960.

12) Craig RG and Powers JM: Restorative dental materials. 11th ed, p 67- 116, Mosby, St Louis, 2002.
13) Oilo G and Gjerdet NR: Dental casting alloys with a low content of noble metals: physical properties. Acta Odontol Scand, 41: 111-116, 1983.
14) Newman MP, Yaman P, Dennison J, Rafter M and Billy E: Fracture resistance of endodontically treated teeth restored with composite posts. J Prosthet Dent, 89: 360-367, 2003.
15) Torbjorner A and Fransson B: A literature review on the prosthetic treatment of structurally compromised teeth. Int J Prosthodont, 17: 369-376, 2004.
16) Maccari PC, Conceição EN and Nunes MF: Fracture resistance of endodontically treated teeth restored with three different prefabricated esthetic posts. J Esthet Restor Dent, 15: 25-30, 2003.
17) Raygot CG, Chai J and Jameson DL: Fracture resistance and primary failure mode of endodontically treated teeth restored with a carbon fiber-reinforced resin post system *in vitro*. Int J Prosthodont, 14: 141-145, 2001.
18) Martinez-Insua A, da Silva L, Rilo B and Santana U: Comparison of the fracture resistances of pulpless teeth restored with a cast post and core or carbon-fiber post with a composite core. J Prosthet Dent, 80: 527-532, 1998.
19) Rosentritt M, Furer C, Behr M, Lang R and Handel G: Comparison of *in vitro* fracture strength of metallic and tooth-coloured posts and cores. J Oral Rehabil, 27: 595-601, 2000.
20) Baldissara P, Di Grazia V, Palano A and Ciocca L: Fatigue resistance of restored endodontically treated teeth: a multiparametric analysis. Int J Prosthodont, 19: 25-27, 2006.
21) Wiskott HW, Nicholls JI and Belser UC: Stress fatigue: basic principles and prosthodontic implications. Int J Prosthodont, 8: 105-116, 1995.
22) Naumann M, Blankenstein F and Dietrich T: Survival of glass fibre reinforced composite post restorations after 2 years-an observational clinical study. J Dent, 33: 305-312, 2005.
23) Mannocci F, Bertelli E, Sherriff M, Watson TF and Ford TR: Three-year clinical comparison of survival of endodontically treated teeth restored with either full cast coverage or with direct composite restoration. J Prosthet Dent, 88: 297-301, 2002.
24) Stegaroiu R, Yamada H, Kusakari H and Miyakawa O: Retention and failure mode after cyclic loading in two post and core systems. J Prosthet Dent, 75: 506-511, 1996.
25) Graf H and Grassl H: A method for measurement of occlusal forces in three directions. Helv Odont Acta, 18: 7-11, 1974.
26) Mohl ND, Zarb GA, Carlsson GE and Rugh JD: A textbook of occlusion. p 143-152, Quintessence, Chicago, 1988.
27) Bates JF, Stafford GD and Harrison A: Masticatory function - a review of the literature. (2). Speed of movement of the mandible, rate of chewing and forces developed in chewing. J Oral Rehabil, 2: 349-361, 1975.
28) Graf H. Bruxism. Dent Clin North Am, 13: 659-665, 1969.
29) Miura H and Hasegawa S: The measurement of physiological tooth displacement in function. J Med Dent Sci, 45: 103-115, 1998.
30) De Backer H, Van Maele G, Decock V and Van den Berghe L: Long-term survival of complete crowns, fixed dental prostheses, and cantilever fixed dental prostheses with posts and cores on root canal-treated teeth. Int J Prosthodont, 20: 229-234, 2007.
31) Jung RE, Kalkstein O, Sailer I, Roos M and Hämmerle CH: A comparison of composite post buildups and cast gold post-and-core buildups for the restoration of nonvital teeth after 5 to 10 years. Int J Prosthodont, 20: 63-69, 2007.
32) Goodacre CJ, Bernal G, Rungcharassaeng K and Kan JYK: Clinical complications in fixed prosthodontics. J Prosthet Dent, 90: 31-41, 2003.
33) De Backer H, Van Maele G, De Moor N, Van den Berghe L and De Boever J: An 18-year retrospective survival study of full crowns with or without posts. Int J Prosthodont, 19: 136-142, 2006.