

## COMPARISON OF TWO METHODS FOR TESTING RESTORED TOOTH FAILURE RESISTANCE

**Juan Marcelo Rosales Rocabado, DDS<sup>1</sup>; Roxana Stegaroiu DDS, PhD<sup>2</sup>;  
Farhana Sharmin DDS, PhD<sup>3</sup>; Eriko Kitamura DDS, PhD<sup>4</sup>;  
Al-amin Bhuiyan, DDS<sup>1</sup>; Kouichi Kurokawa DDS, PhD<sup>2</sup>;  
Katsumi Uoshima DDS, PhD<sup>5</sup>**

<sup>1</sup>*Postgraduate Student, Niigata University Graduate School of Medical and Dental Sciences, Niigata, Japan*

<sup>2</sup>*Associate Professor, Niigata University Graduate School of Medical and Dental Sciences, Niigata, Japan*

<sup>3</sup>*Assistant Professor, Chattagram International Dental College, Chittagong, Bangladesh*

<sup>4</sup>*Assistant Professor, Niigata University Graduate School of Medical and Dental Sciences, Niigata, Japan*

<sup>5</sup>*Professor, Niigata University Graduate School of Medical and Dental Sciences, Niigata, Japan*

### ABSTRACT

**Purpose:** The aim of this study is to investigate the influence of loading test type on the results of failure resistance investigations of teeth restored with post and cores.

**Methods:** Two experimental set-ups were used to compare the failure resistance and failure mode of teeth restored with glass fiber posts and resin core (fiber specimens) with those of teeth restored with cast post and core (cast specimens). In the first experimental set-up, 10 fiber and 10 cast specimens underwent a fatigue test: 2-kg load was buccolingually applied for 900,000 cycles in a wet environment, using a lever-type device. Since specimens did not fail, an additional quasi-static bending test (static test) was performed until failure of the post-tooth complex. In the second experimental set-up, the same number of teeth was identically prepared and restored, but they were submitted to the static test only.

**Results:** Failure resistance and failure mode were separately investigated by the two testing methods. While post type was found to significantly affect failure resistance by both testing methods (t-test,  $p < 0.05$ ), post type significantly influenced failure mode only in the fatigue test (Fisher's exact probability test,  $p < 0.05$ ).

**Conclusions:** If failure resistance is the outcome of interest, testing of teeth restored with posts and cores by a quasi-static bending test alone might be sufficient to predict fracture behavior of restored teeth after an estimated period of 3-4 years of simulated oral function. Conversely, to investigate the influence of dental material aging on failure mode of post-restored teeth, testing under dynamic conditions in wet environment is recommended.

**Key words:** post and core, failure mode, failure resistance, cyclic loading, bending test

### INTRODUCTION

Research work has reported that the efficiency of chewing decreased as the natural occlusion deteriorated; (1) therefore, efforts to restore the natural occlusion have been one of the priorities in dentistry. To accomplish this goal, new materials are constantly introduced into the dental market, and

scientists have been continuously testing their physical, mechanical and biological properties (2). Among these materials, post and cores have been used to restore severe damaged teeth throughout many years. Scientists are constantly testing them to enable development of improved materials and designs that can increase the endurance of post restored teeth to the oral environment. Preceding or

Author for correspondence:

Roxana Stegaroiu, MD, Master's Program of Oral Health and Welfare Science, Graduate School of Medical and Dental Sciences, Niigata University, 2-5274 Gakkocho-Dori, Chuo-ku, Niigata 951-8514, Japan  
email: roxana@dent.niigata-u.ac.jp

complementing clinical studies, laboratory testing plays a significant role in identifying many promising materials, for which in-vitro properties have been closely correlated with clinical performance. (3) Such studies have determined that most of the technical failures in fixed prosthodontics are caused by fatigue fractures. (4)

Fatigue is a mode of fracture whereby a structure eventually fails after being repeatedly subjected to loads that are so small that one application apparently does nothing detrimental to the component. (5) Moreover, fatigue failure has been explained by the development of microscopic cracks in areas of stress concentration, and with continued loading, these cracks fuse to an ever-growing fissure that insidiously weakens the restoration; catastrophic failures results from a final loading cycle that exceeds the mechanical capacity of the remaining sound portion of the material. (5)

To investigate the resistance of different prosthetic materials (post and cores included) to various factors that can lead to mechanical failure, specimens are subjected to specific tests. In the case of fatigue studies, a cyclic loading test is applied: specimens are subjected to repeated loading cycles in a machine that emulates mastication movements. This simulates the effect of occlusion and articulation contacts, which gradually cause strength reduction of the materials (fatigue) (6). Thus, researchers are faced with the challenge of predicting the “fatigue life time” (defined as the total number of cycles to failure under specific loading conditions) of specimens as a first step towards making more accurate predictions and estimates of clinical longevity. (7)

In fatigue studies (8) (9) (10), testing specimens until failure is important to facilitate direct comparison of the damage response of specimens under cyclic loading, providing more reliable and consistent data for comparison with the clinical situation. (7) (11) (12) However in many post and core experiments, in which this method has been employed, few (6) (13) (14) or no failures (15) (8) could be recorded at the end of the tests. In such circumstances, to achieve fractures, quasi-static bending test was applied as a complement of the fatigue test (combination of fatigue and quasi-static bending test). (16)

Nevertheless, fatigue testing is time and resource-consuming (6) and thus, quasi-static bending test is sometimes used independently, as an alternative to fatigue test (7) (17). In quasi-static bending tests, an increasing load is applied on a specimen until failure occurs; this process is sim-

ple, does not need sophisticated equipment, is less time consuming and, therefore, less expensive. (7) For this reason, when applications of new materials or techniques are tested in vitro, there is a tendency among researchers to rather use quasi-static tests than fatigue tests. (9) (10) (12) (17) (18) (19) (20)

However, it is not clear whether material behavior under cyclic loading and quasi-static tests are equivalent. Particularly, fatigue fracture is a serious complication in teeth restored with posts and cores. Manufacturers are continuously developing new posts, claiming these can reduce the risk of tooth fractures as compared with traditional posts, but this has to be appropriately tested. Therefore, the aim of this paper is to study the influence of the loading test type on the results of failure resistance investigations of teeth restored with post and cores.

## MATERIALS AND METHODS

For this study, two different experimental set-ups were used to compare failure resistance and failure mode of 2 post and core types. The results obtained by each experimental method were then compared with each other.

### 1) First experimental set-up: Cyclic loading fatigue test followed by quasi-static bending test

**Tooth Conditions:** Extracted single-canal-rooted premolars were disinfected with 6% sodium hypochlorite solution (Purelox, OYALOX Co., Tokyo, Japan) for one hour. The selection of 20 teeth that were intact, free of caries, cracks or stains and had one root and one canal only was done under the stereomicroscope. All teeth were stored in isotonic saline solution before and after each experimental procedure.

After selection, each tooth was de-coronated with a diamond bur (#104 SHOFU Kyoto, Japan) at the most apical level of the cemento-enamel junction. The root section was flattened with a carborundum disk (Carborundum point CA27, SHOFU), to obtain a surface perpendicular to the longitudinal tooth axis. Then teeth were endodontically treated as shown elsewhere. (16)

According to their mesio-distal, bucal-lingual, and apico-cervical dimensions as measured by a digital caliper, the teeth were divided in 2 groups of similar dimensions. To confirm the allotment of similarly-dimensioned teeth in both groups, a t-test was performed by a commercial computer program (SigmaStat 2.0.3, SPSS, Chicago, IL, USA). The mean dimensions and standard deviations ( $\pm$ ) in the

group of teeth selected to receive fiber posts and resin cores were: 5.11 ( $\pm$  0.51) mm mesio-distally, 7.82 ( $\pm$  0.68) mm bucco-lingually, and 14.29 ( $\pm$  1.43) mm in root length. In the group of teeth selected to receive cast posts and cores, the mean dimensions and standard deviations ( $\pm$ ) were: 5.19 ( $\pm$  0.43) mm mesio-distally, 7.75 ( $\pm$  0.73) mm bucco-lingually, and 14.25 ( $\pm$  1.05) mm in root length. For each dimension, the t-test showed no significant difference between the groups.

**Tooth preparation:** To receive posts of 8 mm length, all canals were prepared using Peeso reamers #1 through #3 (MANI Inc.) with water spray cooling; then tapered reamers #1 and #2 (RTP Reamers, Dentech, Tokyo, Japan) were used. Thereafter, a key way type anti-rotational groove was prepared with a diamond bur (Diamond Point FG, #202, SHOFU Inc.); and the cervical walls were flared using a conical carborundum point (Carborundum point # 27, SHOFU) to simulate preparations required in large caries destructions. The mesiodistal width of the remaining tooth structure in the mesial and distal cervical areas was set at 1 mm on each side. (FIGURE 1a)

**Stone dies:** Impressions were taken with putty and injection type of vinyl polysiloxane impression material (Imprinsic, Tokuyama Dental Co., Tokyo, Japan), using the indirect method. The stone dies were made with extra hard dental stone (Fuji rock, GC Co.).

**Post and core restorations:** Two types of post and core were used to create fiber and cast specimens.

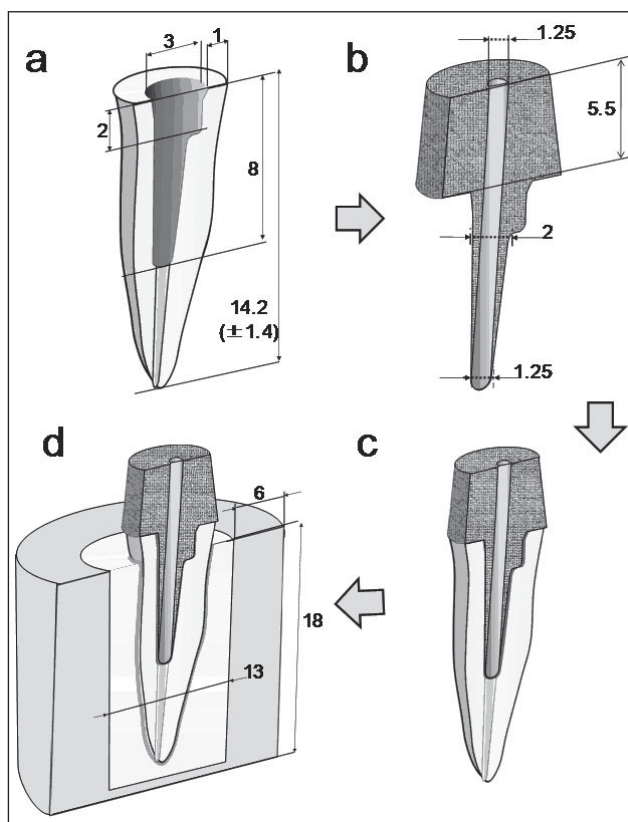
For **fiber specimens**, glass fiber-reinforced composite resin posts (FibreKor, Jeneric/Pentron Inc. Wallingford, CT, USA) of 1.25-mm diameter were selected. To fit the gap between post and dentine in the tapered area of the prepared roots and to build up the core, glass fiber-reinforced core build-up material (Build-it, Jeneric/Pentron Inc.) was used, following manufacturer's instructions. Build-up caps for premolars (Build-it! Core Forms size 3, Jeneric/Pentron Inc.) were used to standardize core dimensions (FIGURE 1b).

For **cast specimens**, wax patterns of dowels and cores were shaped on the stone dies. For core shaping, the same type of build-up caps for premolars, was used to standardize core dimensions. After investing and wax burnout, the mold was cast with a dental alloy that consisted primarily of 46% Ag, 20% Pd, 20% Cu and 12% Au (Castwell M.C., GC Co.).

**Cementation:** Before cementation, all posts and cores were air-particle abraded with a 50 $\mu$ m aluminum oxide abrasive powder and a bonding agent (Bond one, Jeneric/Pentron Inc.) was applied on the surfaces to be cemented, following manufacturer

instructions. In addition in the cast specimens, an alloy primer (Alloy primer, Kuraray Medical Inc, Osaka, Japan) was applied before the bonding agent application. In all the specimens, the dentine surfaces to be cemented were etched with phosphoric acid etching agent (K-etchant Gel, Kuraray Medical Inc., Tokyo, Japan) and the same bonding agent was applied. Cementation was performed with resin cement (Universal C&B: Cement-it, Jeneric/Pentron Inc.), following the manufacture's instructions. (FIGURE 1c). Thereafter, each tooth was kept in saturated humidity at an average temperature of 37°C, using a hotting bath (Magnetic stirrer, TOYO Chemical Laboratories Inc, Tokyo, Japan).

**Resin block embedment:** In all specimens, to simulate the periodontal ligament behavior under load, specimen root surfaces were covered with a cellophane tape (scotch tape) 2 mm below the tooth-core junction and adjusted to perfectly fit; dental cyanon (Dental cyanon, Koatsu Gas Kogyo Co., Chiba, Japan) was used to enhance the adhesion to dentine. Using a surveyor, each specimen was then embedded in a resin block with the long axis of the root parallel to the block's walls, following a method described elsewhere (16) (21). (FIGURE 1 d).



**FIGURE 1.** Specimen dimensions (mm) showed on a fiber specimen. (The same dimensions were set for the cast specimens): a) Root canal preparation; b) Post and core preparation; c) Post and core cementation; d) Resin block embedment.

**Cyclic loading:** Each specimen was mounted into a custom made second class lever-type cyclic testing machine (21). The humid oral environment was simulated by using a strip of gauze set around the tooth-core junction with the end tips introduced into a recipient filled with water. Serrated-type cyclic loading between 0 and 2 Kg (19,62 N) was applied to the buccal surface of the core 4 mm from the tooth-core junction and perpendicular to the specimen axis. A 2.1-mm diameter zirconium ball (Fritsch Labor System, Yokohama, Japan) was used as indenter, to directly contact the core during force application. The load was applied at a rate of 80 strokes per minute; a target of 900,000 cycles was defined. The machine was equipped with 2 types of shutoff sensors to automatically discontinue loading in case of specimen failure; however, if a specimen reached the target without failure, a quasi-static bending test was performed thereafter.

**Quasi-static bending test set-up:** Specimens were placed in an Instron type testing machine (AG-1000E, Shimadzu, Kyoto, Japan) and a load was applied at a crosshead speed of 1 mm/min, in the same direction and at the same location as in the mechanical cycling, until the first sign of specimen failure was recorded. The failure mode was defined from both the force-deflection curve and specimen appearance at the in-situ visual inspection; a small, gradual drop-down in the force curve and the presence of a gap between core and root was defined as debonding. When no gradual drop occurred and no visual gap was apparent, the force was almost linearly increased until a considerable, sharp drop down of the force-deflection curve could be depicted. This corresponded always to a visible fracture of the root and in this case the failure mode was defined as “root fracture”. 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. Thus, specimen mode of failure was classified as either debonding (without root fracture) or root fracture.

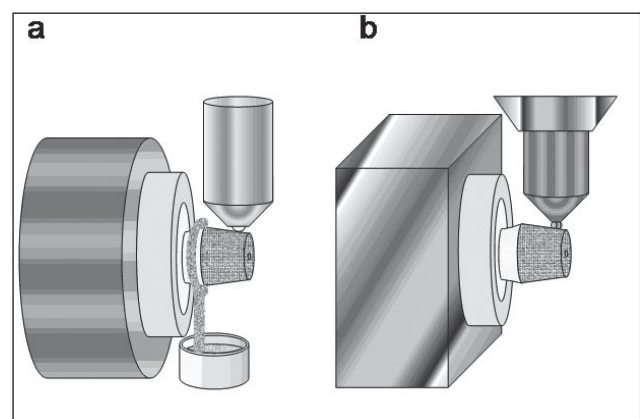
**Statistical analysis of the experimental data:** The failure resistance and failure mode data of the 2 groups were analyzed statistically by the t-test and Fisher’s exact probability test, respectively ( $p < 0.05$ ). The statistical analyses were performed using the above-mentioned commercial computer program (SigmaStat 2.03, SPSS).

## 2) Second experimental set-up: Quasi-static bending test only

For this experimental set-up, other 20 lower premolars were selected and measured as in the

first experimental set-up. Thereafter, the teeth were divided in 2 groups of similar dimensions and a t-test was performed by the same commercial computer program, to confirm the equal distribution of the specimens in both groups. The mean dimensions and standard deviations ( $\pm$ ) of the teeth in the group selected to receive fiber posts and resin cores were: 4.74 ( $\pm$  0.35) mm mesio-ditally, 6.93 ( $\pm$  0.48) mm bucco-lingually, and 13.90 ( $\pm$  1.55) mm in root length. For the teeth in the group selected to receive cast posts and cores, the mean dimensions and standard deviations ( $\pm$ ) were 4.71 ( $\pm$  0.29) mm mesio-ditally, 6.83 ( $\pm$  0.35) mm bucco-lingually, and 14.03 ( $\pm$  1.46) mm in root length. For each dimension, the t-test showed no significant difference between the groups.

The materials and methods used for the preparation of the fiber and cast specimens and their embedment into resin blocks were performed according to the same experimental protocol as in the first experimental set-up. However, the embedded specimens were not submitted to the cyclic loading; and thus, their failure resistance and failure mode were investigated only by the quasi-static bending test. Statistical analyses of the experimental data were performed using the same tests and computer program as for the first experimental set-up.



**FIGURE 2.** Testing methods: a) Specimen in the cycling loading test in wet environment (first experimental set-up); b) Specimen in the bending test (both experimental set-ups).

## RESULTS

### 1) First experimental set-up:

In the cyclic loading test, all the specimens survived the targeted number of cycles; therefore they were afterwards subjected to the quasi-static loading until failure. The failure resistance (load-to failure) means and standard deviations are shown in TABLE 1. After the normal and homogeneous distribution of

the data was confirmed, the 2 groups (fiber and cast specimens) were analyzed statistically by the t-test. Failure resistance showed a statistical difference between the groups ( $p < 0.05$ ) (TABLE 1) with higher values in the cast specimens. Concerning the mode of failure, cast specimens failed by significantly more root fractures (FIGURE 3a) than the fiber specimens (9 versus 3 specimens), (Fisher's exact test:  $p = 0.02$ ). In the rest of the specimens (1 cast and 7 fiber specimens), only debonding (FIGURE 3b) was recorded.

## 2) Second experimental set-up:

The failure resistance (load-to failure) means and standard deviations are shown in TABLE 1. The data was distributed normally and homogeneously, so the t-test was performed. Significantly higher failure resistance was found in the cast than in the fiber specimens ( $p < 0.05$ ). However, in this experimental set-up, no significant difference (Fisher's exact test:  $p = 1.00$ ) could be found in the mode of failure: 8 root fractures (FIGURE 3a) in the cast versus 7 fractures in the fiber specimens. In the rest of the specimens (2 cast and 3 fiber specimens) only debonding (FIGURE 3b) was recorded.

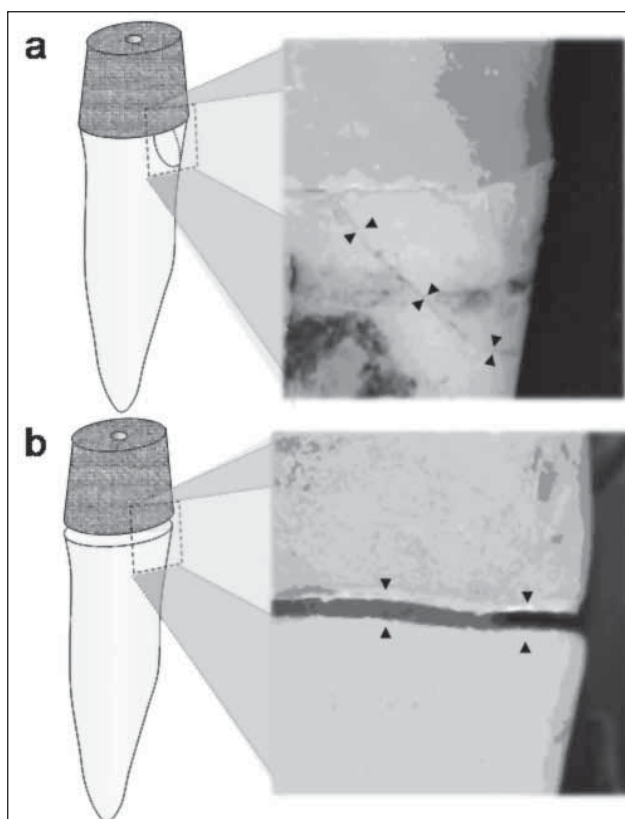
	n	First Experimental set-up	Second Experimental set-up
Fiber specimens	10	18.44 (9.78)	19.27 (6.34)
Cast specimens	10	30.32 (11.67)	27.96 (10.29)
df		18	18
t value		-2.47	-2.27
P value		0.02	0.04

**TABLE 1.** Mean failure resistance in kgf (standard deviation) and the results of the t-test (degrees of freedom (df), t and P values)

## DISCUSSION

The effect of post type (cast or glass-fiber reinforced) on failure resistance and failure mode of restored teeth has been investigated and discussed elsewhere (16); therefore, the discussion will be mainly focused on the similarities and differences found in failure resistance and failure mode by the two experimental set-ups.

In the oral cavity, the restoration "material-bond-tooth" structure is susceptible to chemical, thermal and mechanical influences (22). Out of



**FIGURE 3.** Failure mode (Schematic representation and zoomed-up pictures): a) Tooth fracture (arrowheads show the fracture line); b) Post and core debonding (arrowheads show the gap caused by debonding).

these, high loads that may develop during mastication, swallowing, or parafunctions (such as clenching and bruxism), are expected to have the highest damaging effect on the restored teeth; therefore, in the present study, increasing loads were applied in a quasi-static bending test in both experimental set-ups. Furthermore, the abovementioned external demands on the oral environment, cause cyclic stress patterns in teeth and restorations. This is referred to as "cyclic loading". In combination with other factors such as thermal and chemical influences, cyclic mechanical loading causes a large proportion of dental restoration failures (7). Thus, in the first experimental set-up, before the bending test, a fatigue test was performed to simulate the effect of about 3-4 years of mastication (10) (23) (24). The rate of the cycles (80 cycles/min, that is 1.33 Hz) and the duration of actual loading during each cycle (0.3 s) were set according to the equivalent physiological parameters that have been reportedly measured during mastication. (25) (26)

Regarding force direction, it has been reported that, in vivo, the loading angle in the frontal plane is approximately  $32.5^\circ$  when the load magnitude is at maximum. (7) However, many in vitro experiments,

including the present experimental set-ups, use a force perpendicular to the long axis of the endodontic post (17). The 90 degree angle of incidence between the compressive head and the long axis of the tooth specimen was chosen to simulate the worst case scenario of force application to a restoration (17), and because the specifications for masticatory testing reportedly consisted of emulated mouth motion at 90° of loading angle (22). In the first experimental set-up, the magnitude of the force during cyclic loading was 2 kgf, which is the upper value of the range reported for the lateral force peaks on molars (27). Thus, the mechanical loading protocol set for this study slightly challenged the restored tooth, while still being within the physiological range.

During mechanical testing of teeth, beside the applied loads, tooth constraints need also careful consideration, since they will determine the reaction to those forces. In vivo, the presence of the periodontal ligament with its receptors plays a decisive role in controlling the force level by displacement of the teeth during mastication. (28) In vitro, to reproduce the function of the periodontal ligament, several methods have been suggested. (22) (16) Out of these, the use of cellophane tape wrapped around the tooth root (as in the present study) has been shown to allow a tooth deflection (16) that is similar to that reported in vivo. (29) Similar to other studies, (30) in an attempt to roughly simulate bone, specimens of both experimental set-ups were embedded in an autopolymerizing acrylic resin (modulus of elasticity of approximately 2.4 GPa, (31) which is similar to the average stiffness of cancellous bone. (32)

Mechanical fatigue tests conducted in a humid environment are considered methodologies with high predictability for the clinical performance of different materials and restorative techniques. (15) Therefore, in the first experimental set-up, the cyclic loading was performed in a humid environment, to simulate the long-term effect of saliva's major component (water) on the restorations. The luting agent used for all the specimens is a resin cement; furthermore, the glass-fiber reinforced posts and the core resin in the fiber specimens also include composite resin polymers, all of which, as an effect of aging, can become sensitive to the presence of water. (33) Water can act chemically at crack tips to decrease the strength of glasses, ceramics and composites. (34) Indeed, in the present study, the mechanical cycling in wet environment increased the contact time of the bonding interface

with water, thus increasing the likelihood of debonding. This can explain why significantly more frequent debonding without root fracture were found in the fiber than in the cast specimens by the first experimental set-up, but no significant difference could be found by the second experimental set-up. Therefore, if failure mode of a post-and-core system is the parameter of interest, the selection of the test method should be carefully considered, since different results may be expected in the presence or absence of prolonged cyclic loading in humid environment. To investigate the influence of dental material aging on failure mode of post-restored teeth, testing under dynamic conditions in wet environment is recommended.

Conversely, regardless of experimental set-up, fracture resistance was found to be significantly higher in the cast than the fiber specimens. Therefore, if fracture resistance is the output of interest, a quasi-static bending test alone might be sufficient; its results could be extrapolated to predict fracture behavior after an estimated period of 3-4 years of simulated oral function. However, for longer time span predictions, further studies with fatigue tests of more prolonged cyclic loading are needed.

The results of this study also shade a new light on the way the reader of scientific literature should look at results of laboratory tests of post-restored teeth: Particularly, if failure mode of those teeth is the topic of interest, along with the test results, the test methods and testing conditions should be also carefully considered, to enable an appropriate extrapolation to clinical settings. This is also valid for advertised properties of new dental materials, as claimed in a recent trend of re-thinking the reliability and validity in dental material testing. (3)

## CONCLUSIONS

If failure resistance is the outcome of interest, testing of teeth restored with posts and cores by a quasi-static bending test alone might be sufficient to predict fracture behavior of restored teeth after an estimated period of 3-4 years of simulated oral function. Conversely, to investigate the influence of dental material aging on failure mode of post-restored teeth, testing under dynamic conditions in wet environment is recommended.

## Acknowledgement

*This study was supported in part by a Grant for Promotion of Niigata University Research Projects.*

## REFERENCES

1. **Bates JF, Stafford GD, Harrison A.** Masticatory function – a review of the literature. III. Masticatory performance and efficiency. *Oral Rehabil.* 1976 Jan;3(1):57-67.
2. **Fokkinga WA, Kreulen CM, Bronkhorst EM, Creugers NH.** Composite resin core-crown reconstructions: an up to 17-year follow-up of a controlled clinical trial. *Int J Prosthodont.* 2008 Mar-Apr;21(2):109-15.
3. **Tyas MJ.** Reliability and validity in dental materials testing. *J Dent Res.* 1991 Nov;70(11):1471
4. **Torbjörner A, Fransson B.** A literature review on the prosthetic treatment of structurally compromised teeth. *Int J Prosthodont.* 2004 May-Jun;17(3):369-76.
5. **Wiskott HW, Nicholls JI, Belser UC.** Stress fatigue: basic principles and prosthodontic implications. *Int J Prosthodont.* 1995 Mar-Apr;8(2):105-16.
6. **Huysmans MC, van der Varst PG, Schäfer R, Peters MC, Plasschaert AJ, Soltész U.** Fatigue behavior of direct post-and-core-restored premolars. *J Dent Res.* 1992 May;71(5):1145-50.
7. **Huysmans MC, van der Varst PG.** Mechanical longevity estimation model for post-and-core restorations. *Dental Materials*, Volume 11, Issue 4, July 1995, Pages 252-257.
8. **Baldissara P, Di Grazia V, Palano A, Ciocca L.** Fatigue resistance of restored endodontically treated teeth: a multiparametric analysis. *Int J Prosthodont.* 2006 Jan-Feb;19(1):25-7.
9. **Akkayan B, Gulmez T.** Resistance to fracture of endodontically treated teeth restored with different post systems. *J Prosthet Dent* 2002;87:431-437.
10. **Maccari PC, Conceição EN, Nunes MF.** Fracture resistance of endodontically treated teeth restored with three different prefabricated esthetic posts. *J Esthet Restor Dent* 2003;15:25-30.
11. **Kim J.H., Kim J.W., Myoung S.W., Pines M., and Zhang Y.** Damage maps for Layered Ceramics under Simulated Mastication. *J Dent Res* 87(7):671-675, 2008.
12. **Martinez-Insua A, da Silva L, Rilo B, 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* 1998;80:527-532.
13. **Mannocci F, Ferrari M, Watson TF.** Intermittent loading of teeth restored using quartz fiber, carbon-quartz fiber, and zirconium dioxide ceramic root canal posts. *J Adhes Dent.* 1999;1(2):153-8.
14. **Pontius O, Hutter JW.** Survival rate and fracture strength of incisors restored with different post and core systems and endodontically treated incisors without coronaradicular reinforcement. *J Endod.* 2002 Oct;28(10):710-5.
15. **Scotti R, Valandro LF, Galhano GA, Baldissara P, Bottino MA.** Effect of post length on the fatigue resistance of bovine teeth restored with bonded fiber posts: a pilot study. *Int J Prosthodont.* 2006 Sep-Oct;19(5):504-6.
16. **Sharmin F, Stegaroiu R., Okada N., Kitamura E., Kurokawa K., Nomura S., Miyakawa O.** Effect of post type and cyclic loading on the failure resistance of restored teeth. *Niigata Dental Journal* 2009, 39 (1):11-20.
17. **Cormier CJ, Burns DR, 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* 2001;10:26-36.
18. **Sirimai S, Riis DN, 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* 1999;81:262-269.
19. **Newman MP, Yaman P, Dennison J, Rafter M, Billy E.** Fracture resistance of endodontically treated teeth restored with composite posts. *J Prosthet Dent* 2003;89:360-367.
20. **Raygot CG, Chai J, 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* 2001;14:141-145.
21. **Stegaroiu R, Yamada H, Kusakari H, Miyakawa O.** Retention and failure mode after cyclic loading in two post and core systems. *J Prosthet Dent.* 1996 May;75(5):506-11.
22. **Stappert CF, Chitmongkolsuk S, Silva NR, Att W, Strub JR.** Effect of mouth motion fatigue and thermal cycling on the marginal accuracy of partial coverage restorations made of various dental materials. *Dental Materials*; Volume 24, Issue 9, September 2008, 1248-1257.
23. **Tan PL, Aquilino SA, Gratton DG, Stanford CM, Tan SC, Johnson WT, Dawson D.** In vitro fracture resistance of endodontically treated central incisors with varying ferrule heights and configurations. *J Prosthet Dent.* 2005 Apr;93(4):331-6.
24. **Mohl ND, Zarb GA, Carlsson GE, Rugh JD.** A textbook of occlusion. Chicago (IL): Quintessence Publishing Co. Inc., 1988.
25. **van der Varst PG, Lemmens PL, Peters MC, Plasschaert AJ.** Estimation of the mechanical lifetime of dental restorations: Method and preliminary results. *J Biomech.* 1991;24(5):341-7.
26. **Stanford CM, Brand RA.** Toward an understanding of implant occlusion and strain adaptive bone modeling and remodeling. *J Prosthet Dent.* 1999 May;81(5):553-61.
27. **Mannocci F, Bertelli E, Sherriff M, Watson TF, 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.* 2002 Sep;88(3):297-301.
28. **Johnsen SE, Svensson KG, Trulsson M.** Forces applied by anterior and posterior teeth and roles of periodontal afferents during hold-and-split tasks in human subjects. *Exp Brain Res.* 2007 Mar;178(1):126-34. Epub 2006 Oct 10.
29. **Miura H, Hasegawa S, Okada D, Ishihara H.** The measurement of physiological tooth displacement in function. *Dent Sci.* 1998 Jun;45(2):103-15.
30. **Att W, Kurun S, Gerds T, Strub JR.** Fracture resistance of single-tooth implant-supported all-ceramic restorations: an in vitro study. *J Prosthet Dent.* 2006 Feb;95(2):111-6.
31. **Nakayama WT, Hall DR, Grenoble DE, Katz JL.** Elastic properties of dental resin restorative materials. *J Dent Res* 1974; 53:1121-1126.
32. **Rho JY, Ashman RB, Turner CH.** Young's modulus of trabecular and cortical bone material: Ultrasonic and microtensile measurements. *J Biomech* 1993;26:111-119.
33. **De Munck J, Van Meerbeek B, Yoshida Y, Inoue S, Vargas M, Suzuki K, Lambrechts P, Vanherle G** Four-year water degradation of total-etch adhesives bonded to dentin. *J Dent Res.* 2003 Feb;82(2):136-40.
34. **J. Robert Kelly, DDS, MS, DMedSc.** Clinically relevant approach to failure testing of all-ceramic restorations. *J Prosthet Dent* 1999; Vol.81(6):652-61.