A composite resin core with a new zirconia tube reduces the surface strain at the cervical area of a mandibular molar: A model tooth study

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Abstract

Purpose: This study aimed to evaluate the surface strain at the cervical area of endodontically treated molars with a large pulp chamber restored using a composite resin core with three different types of core build-up systems.

Methods: Reproduction models of human mandibular molars with prepared post spaces were used in this study. Roots duplicated with a composite resin were used as the experimental teeth. Three types of core build-up systems were used: composite resin core (RC), composite resin core with fiber posts (FC), and composite resin core with a prefabricated zirconia tube (ZC). Each group comprised eight specimens. Crowns made of yttria partially stabilized zirconia were cemented with dual-cure resin cement. Four strain gauges were attached to the surfaces of each specimen: the cervical area of the root and crown, on the buccal and lingual sides. The surface strain at each cervical area was measured using a static loading test and statistically analyzed.

Results: In the case of static loading to the buccal cusp inner slope, ZC showed a significantly lower strain than RC in the crown on the buccal side and in the root and FC in the root. In the central fossa, ZC showed a significantly lower strain than FC in the root on the lingual side.

Conclusion: The prefabricated zirconia tube reduced the surface strain at the cervical area of the buccal/lingual root in molars; however, the effect was small in the cervical area of the crown.

Keywords: Zirconia tube, Stress distribution, Surface strain, Post and core materials, Core build-up

Received 23 September 2021, Accepted 26 January 2022, Available online 4 March 2022

1. Introduction

Endodontically treated teeth that lose significant coronal tooth structure are restored with core build-up systems for the final restoration. The cast post and core are typically used because of their fracture resistance and good fit in post spaces[1–4]. However, teeth restored with these systems often show vertical root fractures because the difference in elastic modulus between the root dentin and metal increases the stress concentration at the apex of the post[5]. Adhesion to dentin and the mechanical properties of the composite resin has recently improved[6]. Because the elastic modulus of the composite resin is similar to that of dentin, the core build-up systems using a composite resin effectively prevent vertical root fractures[7]. However, various materials are used to reinforce composite resin cores because they do not have a high fracture strength[8].

Prefabricated glass fiber posts are often used to enhance the strength of composite resin[9,10]. However, some studies have suggested that endodontically treated teeth restored using resin composites can increase the stress concentration at the cervical area of the tooth[11,12]. Luting agent failure occurs when functional stress causes excessive marginal deformation of the root and the restoration[13]. In a model study, high microleakage was observed for teeth restored with a flexible fiber post compared to a rigid post[14]. Therefore, microleakage may be caused by stress concentration in the cervical area, resulting in luting agent failure. Guzy et al. demonstrated that stress in the cervical area was higher on the surface of the tooth structure than in its center[15], indicating that strengthening would be more effective near the former than the latter.

We reported that cylindrical glass fiber sleeves reinforce the surface structure of teeth with flared root canals restored using a composite resin[8,16]. In molars with large pulp chambers, it is difficult for glass fiber posts to prevent stress concentration at the cervical area of the tooth and reinforce a composite resin core. In addition, post-
space preparation carries the risk of perforation and thinning of the remaining tooth structure. The development of adhesive dentistry with minimal intervention has enabled treatment without radicular posts, such as endocrowns, in endodontically treated molars[17–19]. Therefore, we created a new core build-up material, a zirconia tube to reinforce near the surface at the cervical area of an endodontically treated molar, as an alternative to radicular posts. Zirconia has adhesion to composite resins, high mechanical strength, high stability, and biocompatibility, and it is clinically used as a material for crowns and fixed partial dentures[20]. Accordingly, the new core build-up system locates a zirconia tube in the pulp chamber without using radicular posts, to increase the resistance against the stress concentration at the cervical area of molars restored using a composite resin core.

Various methods have been employed to analyze the stress distribution under load on teeth, including strain gauge methods[21–25], photoelastic methods[26,27], and finite element analysis (FEA)[28–30]. Photoelastic methods and FEA evaluate the stress distribution within the models based on the material’s mechanical properties. This study employed strain gauge methods, as they can measure the magnitude of surface strains by considering the effect of clinical techniques such as polymerization shrinkage, using a clinically simulated model made of the actual materials[31].

This study aimed to evaluate the surface strain at the cervical area of structurally compromised molars with large pulp chambers restored using three different types of composite resin core build-up systems. Our hypothesis was that the zirconia tube reinforcing the cervical area in endodontically treated molars would restrain the surface strain at the cervical area compared with other composite resin cores.

2. Materials and Methods

2.1. Fabrication of experimental root

A duplicated model of a human mandibular second molar with prepared post spaces (B12-51-#47, Nissin Dental Products Inc., Kyoto, Japan) was used as the experimental master model in this study. This

model was also used to measure the surface strain magnitude of roots and zirconia-fixed partial dentures in our previous study[21,22]. The model was prepared with three post spaces (mesio-buccal, mesio-lingual, and distal) using a cylindrical drill with an apex diameter of 1.17 mm and a taper rate of 0.05. Their depths from the pulp chamber floor to the apex of the post space were 2.0 mm, 3.0 mm, and 4.0 mm, respectively. The depth from the pulp chamber to the coronal area was 3.5 mm. The thickness and height of the coronal tooth structure for ferrule preparation were 1.0 mm and 1.0 mm, respectively. The finish line design was a deep-chamfer type. The width of the deep chamfer was 0.5 mm (Fig. 1).

An impression of the duplicated model was made using a transparent high-strength addition-cure-type silicon impression material (KE-1603-A/B, Shin-Etsu Chemical Co., Ltd., Tokyo, Japan). The impression was used as a mold to duplicate the model. An automix composite resin (Clearfil DC Core Automix, Kuraray Noritake Dental, Tokyo, Japan) was injected into the mold and light-cured from the occlusal, buccal, lingual, mesial, distal, and root sides for 20 s each. The experimental roots were fabricated using this method with a composite resin.

2.2. Fabrication of a prefabricated zirconia tube

Three mol% yttria partially stabilized zirconia powder (TZ-3YSB-E, Tosoh Corporation, Tokyo, Japan) was placed in a cylindrical mold and pressed at 20 MPa for 1 min to form cylindrical zirconia. The cylindrical zirconia was shaped into tubular zirconia using a lathe or rotary cutting tool. The tubular zirconia was subsequently sintered at 1450°C for 2 h to finally form a prefabricate zirconia tube with an outer diameter of 5.0 mm, height of 5.0 mm, and thickness of 0.7 mm (Fig. 2).

2.3. Core build-up

Three types of core build-up systems were used (Fig. 3): composite resin core (RC), composite resin core with fiber posts (FC), and composite resin core with a prefabricated zirconia tube (ZC). Each group comprised eight specimens. The surfaces of the experimental roots were subjected to 40% phosphoric acid gel (K-etchant GEL, Kuraray Noritake Dental) for 5 s, cleaned with water, and dried with air and paper points. Subsequently, the surface of the coronal tooth structure and post spaces were applied with a ceramic primer (Clearfil Ceramic Primer Plus, Kuraray Noritake Dental) and dried with air and paper points. The surface of the coronal tooth structure and the post spaces of the specimens were applied with a bonding
Fig. 3. Experimental groups. RC: composite resin core, FC: composite resin core with prefabricated fiber posts, ZC: composite resin core with a prefabricated zirconia tube. (a) Monolithic zirconia crown, (b) Composite resin, (c) Prefabricated glass fiber post, (d) Prefabricated zirconia tube, (e) Experimental root made of a composite resin.

agent (Clearfil Universal Bond Quick, Kuraray Noritake Dental) for 10 s. Mild air was applied to the post spaces to spread a thin layer of the bonding agent, and the surplus bonding agent of the post spaces was removed using paper points. The surfaces of the experimental roots were cured using curing light with an intensity of 650 mW/cm² for 20 s using a light-curing unit (Blueshot, Shofu, Kyoto, Japan). The mold was fabricated using a transparent high-strength addition-cure-type silicon impression material (KE-1603-A/B, Shin-etsu Chemical Co., Ltd.) to maintain the shape of the core.

2.3.1. Composite resin core

An automix composite resin was injected into the post spaces of the surface-treated experimental root as described above and then light-cured from the occlusal side for 20 s. The abutment was built up with an automix composite resin using the mold and was light-cured on the occlusal, buccal, and lingual sides for 20 s each. The excess composite resin was removed using a hand-cutting instrument. Subsequently, the specimens were light-cured from the buccal, lingual, and occlusal sides for 20 s each. The specimens were then stored at room temperature for 24 h. The height and chamfer width of the abutment was adjusted to 5.0 mm and 0.5 mm, respectively, using a diamond bur with a water coolant. Nakamura et al. previously reported that monolithic zirconia crowns could withstand the forces in the molar region, even with a minimal thickness of 0.5 mm [32].

2.3.2. Composite resin core with prefabricated glass fiber posts

The glass fiber posts (Clearfil Fiber Post #4, Kuraray Noritake Dental) were cut 3.0 mm above the finish line of the crown. The glass fiber posts were etched with 40% phosphoric acid gel (K-etchant GEL, Kuraray Noritake Dental) for 5 s and cleansed with distilled water. The surfaces of the abutments were applied with 40% phosphoric acid gel (K-etchant GEL, Kuraray Noritake Dental) for 5 s and cleansed with distilled water. The surfaces of the abutments were air-dried, coated with a ceramic primer (Clearfil Ceramic Primer Plus, Kuraray Noritake Dental), and dried with air. Subsequently, the surfaces of the abutments were coated with a tooth primer (Clearfil Ceramic Primer Plus, Kuraray Noritake Dental). The crowns were cured using a dual-curing resin cement (Panavia V5, Kuraray Noritake Dental) under finger pressure according to the manufacturer’s instructions.

2.3.3. Composite resin core with a prefabricated zirconia tube

The surface of a prefabricated zirconia tube was sandblasted with 70 µm Al₂O₃ (HIALUMINAS, Shofu, Kyoto, Japan) from a distance of 10 mm at 0.2 MPa for 30 s. Kern et al. suggested that 10-methacyryloyloxydecyl dihydrogen phosphate (MDP) improves the adhesion between zirconia and composite resin [33]. The zirconia tube was coated with an MDP-containing ceramic primer (Clearfil Ceramic Primer Plus, Kuraray Noritake Dental). An automix composite resin was injected into the post spaces of the surface-treated experimental root as described above, while a prefabricated zirconia tube was inserted into the pulp chamber. The top of the prefabricated zirconia tube was located 3.0 mm above the finish line of the crown. The abutment was built and adjusted as described above.

2.4. Fabrication of crown

The surfaces of the abutments were coated with imaging powder (CEREC Optispray, Dentsply Sirona). The abutments were scanned using an extra oral scanner (AutoScan DS-EX Pro, Shining 3D Tech. Co., Ltd., Hangzhou, China), and crowns were designed using a double-scan technique in which an additional specimen cemented the master crown. The internal space for the cement was programmed to be 0 µm from to 1 mm above the finish line, 80 µm for the other, and a minimum crown thickness of 0.5 mm. Subsequently, monolithic zirconia crowns were milled from pre-sintered zirconia disks (Katana HTML, Kuraray Noritake Dental) using a five-axis milling machine (MD 500, Canon Electronics Inc., Tokyo, Japan). Thereafter, the specimens were introduced in a speed sintering furnace (inFire HTC, Dentsply Sirona) at 1500°C for 2 h.

The inner surfaces of the crowns were sandblasted with 70 µm Al₂O₃ from a distance of 10 mm at 0.2 MPa for 30 s and coated with a ceramic primer (Clearfil Ceramic Primer Plus, Kuraray Noritake Dental). The surfaces of the abutments were applied with 40% phosphoric acid gel (K-etchant GEL, Kuraray Noritake Dental) for 5 s and cleansed with distilled water. The surfaces of the abutments were air-dried, coated with a ceramic primer (Clearfil Ceramic Primer Plus, Kuraray Noritake Dental), and dried with air. Subsequently, the surfaces of the abutments were coated with a tooth primer (Panavia V5 tooth primer, Kuraray Noritake Dental). The crowns were cemented with a dual-curing resin cement (Panavia V5, Kuraray Noritake Dental) under finger pressure according to the manufacturer’s instructions.

2.5. Measurement of strains

In this study, the surface strain of the crowns and roots in the cervical area was evaluated using the strain gauge method. Four gauges were attached to the cervical area of the crown and the root just above and below the finish line on the buccal and lingual sides (Fig. 4). The adhesion surfaces of the crowns and roots were sandblasted with 70 µm Al₂O₃ (HI ALUMINAS) from a distance of 10 mm at 0.2 MPa for 10 s and 5 s, respectively. Strain gauges with a length of 1.6 mm and a width of 1.2 mm (KFRB-02N-120-C1-16 N30C2, Kyowa Electronic Instruments Co., Ltd., Tokyo, Japan) were attached to the crowns and roots with a strain gauge cement (CC-33A, Kyowa Electronic Instruments Co., Ltd.), while applying finger pressure via a polyethylene film for 1 min. The specimens were stored at room temperature for 24 h.

Roots of experimental specimens were embedded to 3.0 mm below the finish line of the crown in an acrylic resin (Palapress vario, Heraeus Kulzer) (Fig. 4). Roots were enveloped with a layer of vinyl polysiloxane material (Correct Quick, Pentron Co., Wallingford, CT, USA) with a thickness of 0.25 mm simulating the periodontal ligament.
Fig. 4. Schematic representation of the embedded experimental specimens and loading points (A: Buccal cusp inner slope, B: Central fossa). (a) Acrylic resin, (b) Aluminum ring, (c) Vinyl polysiloxane impression material, (SC) Strain gauge attached to crown, (SR) Strain gauge attached to root, (ZT) Zirconia tube.

Loads were applied perpendicular to the occlusal surfaces of the experimental specimen using a universal testing machine (Autograph AGS-H, Shimadzu, Kyoto, Japan) via a platinum gold foil with a crosshead speed of 1.0 mm/min at up to 200 N using a ball end 2.0 mm in diameter. In this study, a load of 200 N was selected to simulate the effect of mastication on the surface strain because some studies have reported that the physiological biting force of the molar during mastication was found to be between approximately 164 N and 200 N[12,34]. The loading points were the buccal cusp inner slope and central fossa (Fig. 4). The data measured from the four strain gauges were recorded using a software (DCS-100A, Kyowa Electronic Instrument Co., Ltd.) via a sensor interface (300 B, Kyowa Electronic Instruments Co., Ltd.). The measured data were corrected using gauge rate. Positive and negative values of the measured data indicate tensile strain and compressive strain, respectively.

2.6. Statistical analyses

Statistical analyses were performed using the Statistical Package for the Social Sciences (SPSS version 22.0; IBM Corp., Armonk, NY, USA). The effect of the resin core type on each surface strain magnitude at each loading location was tested using the Kruskal-Wallis test, while post-hoc multiple comparisons were made using the Mann-Whitney U test with Bonferroni correction. A significant difference was observed at p < 0.05.

3. Results

The mean values of the surface strains are presented in Table 1. The Kruskal-Wallis test indicated that the composite resin core type had a significant effect on the surface strains in the crown on the buccal side, and in the root on the buccal and lingual sides in loading on the buccal cusp inner slope and on the lingual side in loading on the central fossa (p < 0.05). In the case of loading on the buccal cusp inner slope, ZC showed a significantly lower strain than RC in the crown on the buccal side (p = 0.006). In the root, ZC showed a significantly lower strain than RC and FC on the buccal and lingual sides (p < 0.001–0.015). In the case of central fossa loading, ZC showed a significantly lower strain than FC in the root on the lingual side (p = 0.003).

4. Discussion

The effect of three types of core build-up systems on the surface strain at the cervical area of monolithic zirconia crowns and roots was investigated in this study. The hypothesis that endodontically treated molars reinforcing the cervical area using the zirconia tube would restrain the surface strain at the cervical area compared with other composite resin cores is supported by our experimental results. It is important to understand the effect of the mechanical properties of restorative materials on the biomechanical behavior of endodontically treated teeth under load. During mastication, stress and strain are generated in the teeth. Stress and strain generally have no negative effects; in fact, they are important for maintaining biological and structural homeostasis. However, structural failure can occur when the strain exceeds the elastic limit owing to excessive stress[35]. Some studies have shown that endodontically treated teeth restored with composite resin cores have increased stress concentration at the cervical area of the tooth structure[11,12]. This stress can cause failure of the luting agent and marginal microleakage[14]. Therefore, we aimed to create a new core build-up system in which the retention of the core depends on the adhesion by improving the resistance to this stress, rather than posts, which have the risk of weakening the remaining tooth structure. Hence, we evaluated the effect of improving the resistance to this stress by using a prefabricated zirconia tube on the surface strain at the cervical area.

As a result of the load to the buccal cusp inner slope, the crown on the buccal side of the ZC showed a significantly lower strain than the RC. In the root, both on the buccal and lingual sides, ZC showed a significantly lower strain than RC and FC. The results of the crown surface strain are supported by a study in which the absence of posts resulted in higher strain in coronal reconstruction[11]. Guzy et al. reported that endodontically treated teeth have a higher strain at the cervical area on the surface than at the center[15]. As a result of the root surface strain, reinforcing the surface of the cervical area by the zirconia tube could have prevented the distortion of the root compared with other types of composite resin core build-up systems. As a result of the experiment in the central fossa, FC showed a higher strain than ZC on the lingual side. Dejak et al. reported that mandibular molars show stress concentration on the lingual side of the cervical area[34]. ZC showed lower strain than FC because the zirconia tube could have prevented the distortion of the root for the same reason as the experimental load on the buccal cusp inner slope. The zirconia tube prevented the deformation of the cervical area more than other core build-up systems may be related to the integration of the root dentin and the composite resin with the rigid zirconia tube, as zirconia has a high elastic modulus and adheres to the composite resin.

Junge et al. reported that excessive surface strain on the margin of the restorations and roots during function caused failure of the luting agents[13]. Failure of the luting agent leads to microleakage and secondary caries. In addition, Chang et al. suggested that more microleakage was observed for teeth restored with a flexible post, such as a fiber post than those restored with a rigid post[14]. A new composite resin core build-up using a zirconia tube showed a lower surface strain than other types of composite resin core by reinforcing near the surface at the cervical area. Therefore, it is possible that this new core build-up performs well during mastication with the objective of preventing microleakage and secondary caries.

In this study, the experimental roots were made of composite
resin with an elastic modulus close to that of dentin[36,37]. However, the materials used in this study have different physical properties and characteristics, including hardness, fracture toughness, and bond strength to resin materials in addition to the elastic modulus. Differences in the physical properties of the composite resin and dentin may have influenced the results. The roots of actual human molars have complex and diverse morphologies, making it difficult to standardize the specimens. Therefore, the roots were fabricated using composite resin to obtain reliable measurements of surface strain, which was the focus of this study. In the future, it will be necessary to perform cyclic loading tests, thermal cyclic tests, and fracture tests using bovine teeth and human teeth to validate the findings of this study.

The direct technique of composite resin core restorations was selected in this study because of the principle of minimal intervention[38] and good bonding performance[39] compared with those of the indirect technique. When the composite resin core is built using the direct method, the time from the core build-up to the start of tooth preparation may affect the adhesion and polymerization of the composite resin. Saygili et al. reported that the preparation of cemented post cores using a high-speed handpiece had a significantly negative effect on retention when performed 15 min after cementation.[40] Therefore, in this study, tooth preparation was carried out 24 h after the composite resin core build-up.

In this study, strain gauge methods were used for a simulated experimental model. In previous studies of stress concentration on endodontically treated teeth restored using different materials under simulated load, FEA[28–30] and strain gauge methods[21–25] have been used. FEA methods can measure the distribution and magnitude of internal stress in simulated models. However, FEA results may be affected by the way the model is assembled and the physical properties of the materials. Libman et al. reported that strain gauges could detect the existence of a crack and micromovements of the crown margins that could not be observed by the unaided eye.[41] This study employed the strain gauge method with a simulated experimental model because strain gauge methods can measure the surface strains by considering the effect of clinical techniques such as polymerization shrinkage[31]. Dejak et al. reported that stress increases in the cervical area of the lingual side of the mandibular molar during mastication[34]. In this study, strain gauges were attached to the surfaces of each specimen: the cervical area of the root and crown, on the buccal and lingual sides. The loading points were positioned at the buccal cusp inner slope and the central fossa in the mandibular molar. During mastication, these points contact the opposite molar. In this study, to evaluate the clinical effects of the mechanical properties of core build-up systems on the micromovement of crowns and roots under a load, the magnitude of the surface strain at the cervical area of the monolithic zirconia crowns and roots were measured using the strain gauge method.

This static load test did not perfectly reproduce the oral environment. The remaining dentin walls varied clinically. This new core build-up system cannot be used for all endodontically treated molars, as it requires a wide and deep pulp chamber. Moreover, the oral environment is moist with saliva, and complex loads are repeatedly applied to the teeth during function. Restorative materials are physically and chemically affected by these conditions. Therefore, it is necessary for future studies to evaluate the effects of crown, root, and luting agents using cyclic loading and thermal cycling tests. Barcelos et al. suggested that, in molars, stress was increased in the cervical area and the furcation area[11]. Therefore, further studies are needed to investigate the effect of loading seen when using the composite resin core build-up system with a zirconia crown in endodontically treated molars. With the development of adhesive and digital dentistry, endocrowns made of various materials without radicular posts have been clinically selected for endodontically treated molars[17–19]. In the future, it will be necessary to compare teeth restored using this new core build-up material with those restored using endocrowns in terms of their functional biomechanical behavior.

### 5. Conclusion

In this study, a zirconia tube significantly reinforced the cervical area in the buccal and lingual roots of an endodontically treated model molar restored using a composite resin core; however, the effect was small in the cervical area of the monolithic zirconia crown. These findings suggest that reinforcing the composite resin core with a zirconia tube may prevent microleakage in the cervical area of the crown. However, experiments performed under clinical conditions are necessary to further validate the effect of reinforcement.

### Acknowledgements

The authors would like to appreciate the members of the Department of Masticatory Function and Health Science, Division of Oral Health Sciences, Graduate School of Medical and Dental Sciences, Tokyo Medical and Dental University, for their cooperation in this study. This study was funded by Grants-in-Aid for Scientific Research from Japan Society for the Promotion of Science (JSPS No.16K11587, No.18K17113 and No.21K09973).

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<th>Table 1. Mean (standard deviation) of the surface strain (με) in the experimental groups (n = 8).</th>
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Groups with different superscript letter show significant difference on each loading point in each strain gauge (p < 0.05). RC: composite resin core, FC: composite resin core with prefabricated fiber posts, ZC: composite resin core with a prefabricated zirconia tube.
Conflicts of interest

The authors have declared that no conflict of interest exists.

References


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