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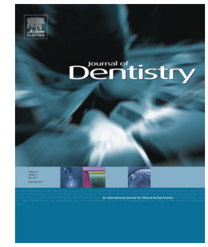

The effects of ferrule configuration on the anti-fracture ability of fiber post-restored teeth

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ARTICLE INFO

Article history:
Received 11 March 2014
Received in revised form
15 September 2014
Accepted 9 October 2014

Keywords:
Extended finite element method
Fracture failure
Post-restored teeth
Ferrule

ABSTRACT

Objectives: To evaluate the fracture resistance of fibre post-restored teeth with various ferrule configurations by using fracture failure tests and extended finite element analysis (XFEM).

Methods: 60 Maxillary central incisors were collected and divided into six groups ($n = 10$) according to various ferrule configurations with different ferrule heights in the labial or palatal region. All of the teeth were endodontically treated and restored by using fibre posts, composite cores and metal crowns. Fracture failure tests were performed on the post retained restorations until fracture occurred. The ultimate load was recorded and analyzed by one way analysis of variance (ANOVA). The fractured specimens were longitudinal sectioned and investigated by micro-stereomicroscope and scanning electronic microscope. XFEM was used to model the fracture of the post-restored teeth and exhibit crack initiation and propagation in the cement layers.

Results: Fracture failure tests indicated that the palatal ferrule significantly enhanced the fracture resistance of the post-restored teeth, regardless the height of the labial ferrule. The fractography investigation exhibited that the crack initiated at the palatal margin of the cement layer and propagated to the cervical region of the root. XFEM confirmed these findings and demonstrated that increasing of the palatal ferrule could effectively enhance the anti-fracture ability of the adhesive cement and protected the integrity of adhesive cement.

Conclusion: Adhesive interface was the susceptible structure of the post retained restorations. Increasing palatal ferrule height could effectively reduce the stress concentrated within the palatal adhesive cement.

Clinical Significance: ‘‘Ferrule effect’’ exhibits the protection of the interity of cement layer. Increasing the ferrule height, especially in the palatal side, can significantly enhance the anti-fracture ability of fibre post-restored teeth.

1. Introduction

The restoration of endodontically treated teeth still represents a challenging task for clinicians. The task is complicated by substantial loss of coronal tooth structure and the ability to predict restorative long-term success. It has been disputed whether the mechanical properties of dental hard tissues, such as modulus of elasticity, compressive strength, or brittleness, would change after endodontic treatment.[1] However,

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http://dx.doi.org/10.1016/j.jdent.2014.10.003

endodontically treated teeth were claimed to be weaker and more prone to fracture than vital teeth, according to the clinical observations.[2] The loss of structural integrity might contribute primarily to the vulnerability of endodontically treated teeth and their reduced resistance to fracture.[1] The likelihood of survival of a post-retained restoration thus directly related to the quantity and quality of the remaining tooth structure and the efficiency of the restorative procedures used to replace lost structural integrity.[3]

Although restorative methods affect the fracture resistance and fracture mode of post-restored teeth at a certain extent,[4] preserving intact coronal tooth structure and maintaining cervical tissue are still considered to be more crucial to optimize the biomechanical behaviour of the endodontically treated teeth.[2,5–8] Parallel walls of dentine extending coronally from the crown margin provide a ferrule, which after being encircled by a crown provides a protective effect by reducing stresses within a tooth called the ''ferrule effect''.[9] The result is an elevation in resistance form of the crown from the fracture of tooth structure. It has been proved both in laboratorial investigation and clinical observations that the less coronal dentine remains, the weaker the fracture resistance of endodontically treated teeth.[10,11] It has been proposed that 1.5 mm coronal dentine is necessary for the long-term survival of restoration.[12–14] In the clinical situation, however, the ideal status of circumferential ferrule with adequate and uniform height could not be always achieved. A tooth with varying ferrule configurations, especially absence of the labial or palatal wall, really plagued dentists in the clinical practice. Ng et al.[15] have declared that the coronal dentine on the palatal aspect plays more important roles in the anti-fracture ability of endodontically treated teeth than those on the labial ones. Nevertheless, the effects of the various ferrule configurations on the fracture resistance of post-retained restorations have not been comprehensively investigated.

For the restorations of endodontically treated teeth, clinical observations and experimental investigations have shown that the fracture of residual dentine or loosening of the post-core assembly reflects a major mode of failure.[16,17] Unexpected damage accumulation and interfacial debonding decrease the mechanical properties of luting agents, then lead to entire failure of the post-restored crown. Thus, a full understanding of stress fields developed in the restoration and tooth becomes particularly important, especially for the weaker structures such as the cement layers.

Finite element analysis (FEA) is a promising approach for investigating the biomechanics in dentistry, which allows bioengineering virtual simulations of oral environments.[18] However, the reliability of these results deducing in the clinical practice is still under suspicion. A hypothesis that the structure would be intact during the whole loading period was often adopted in the FEA studies, which is obviously not consistent with the complexity of clinical process.[19] The present study attempts to use isotropic damage initiation criteria in conjunction with the extended finite element method (XFEM) to model the fracture of the post-restored teeth and exhibit crack initiation and propagation in cement layers. XFEM is a method developed for computationally predicting crack initiation and propagation, which has recently been successfully applied in solving medical problems, simulating dynamic fracture, fatigue, and various crack patterns in brittle materials.[20–23] Compared with conventional discontinuous analysis, one of the main advantages of XFEM is that it not only allows automatic initiation and propagation of cracks modelled without predefining in isotropic elastic materials, but also avoids the requirement of elements remeshing during crack extension.[21,24] Another major advantage of the method is that more accurate results can be acquired by increasing the degrees of freedom in the failure element only.[25]

The objective of the present study was to investigate the influence of ferrule configurations on the fracture process of fibre post-retained teeth by using a combined method of fracture failure test and XFEM. The null hypothesis was that fracture resistance does not vary as a function of the ferrule configuration.

2. Materials and methods

A combined experimental and numerical method was used to evaluate the mechanical performance of fibre post-restored teeth with various ferrule configurations under external loads.

2.1. *In vitro tests*

The study protocol was approved by the Ethics Committee of the School and Hospital of Stomatology, Wuhan University. Patients who donated their teeth were informed of the purposes of the study. Written informed consents were obtained prior to teeth extraction.

2.2. *Fabrication of post retained restorations*

Sixty intact human maxillary incisors were collected directly after extraction and stored in 0.1% thymol solution less than 3 months. The teeth were randomly assigned to six groups and embedded in acrylic resin at the level of 2 mm below the cemento-enamel junction (CEJ). A thin coating of silicone on the roots, approximate 0.2–0.3 mm in thickness, were made to imitate a human periodontal ligament periodontium. To confirm the even size distribution within groups, the root lengths (from the root apex to the proximal CEJ), the mesio-distal and labial-palatal dimensions of the teeth were measured (at the level of the CEJ) using a calliper (LA-7, Peacock Inc., Tokyo, Japan). Overall, the mean of root length was 13.5 ± 1.5 mm, while the means of mesio-distal and labial-palatal dimensions were 6.1 ± 0.5 mm and 7.5 ± 0.7 mm.

The specimens were endodontically prepared using a crown-down technique by ProTaper (Dentsply-Maillefer, Konstanz, Swizerland) and then filled by gutta-percha (Lexicon Gutta Percha Points, Dentsply, Tulsa, OK, USA) and sealer (AH plus, Dentsply/De Trey, Constance, Germany). The teeth were decoronated at six levels to the most labial and palatal points of CEJ, based on the ferrule configurations (Fig. 1B1–B6):

Group 1 (as negative control): 0 mm labial ferrule and 0 mm palatal ferrule.

Group 2: 1 mm labial ferrule and 0 mm palatal ferrule.

Group 3: 2 mm labial ferrule and 0 mm palatal ferrule.

Group 4: 0 mm labial ferrule and 1 mm palatal ferrule.

Group 5: 0 mm labial ferrule and 2 mm palatal ferrule.