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Advances in Three-dimensional Finite Element Analysis of Non-carious Cervical Defects

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Abstract: Three dimensional finite element analysis (FEA) is an important tool in biomechanical analysis research and has been widely applied used in the field of oral biomechanics research. Non carious neck defects (NCCL) are a common and frequently occurring disease in clinical practice. Using FEA to study the stress distribution of teeth before and after NCCL treatment can provide reference and guidance for the treatment of non carious neck defects in clinical practice. This article will discuss the application of FEA in a review on the progress of NCCL repair methods and repair materials in therapeutic research.

Keywords: Non Carious Neck Defect; Finite Element Analysis; Inlay.

1. Introduction

Non-carious cervical defect refers to the loss of hard tissue at the enamel-cementum boundary of the tooth neck, which can be accompanied by dentin hypersensitivity, and is one of the common diseases in the Department of Stomatology [1]. Because of the limitation of the oral environment, there are some limitations in the study of its etiology and different repair methods. However, it is effective and convenient to simulate the oral condition by simulating the mechanical loading of the neck defect with three-dimensional finite element method, may make certain instruction for the actual work.

2. Application of Finite Element Method in the Study of the Etiology of Non-Carious Cervical Defects

The non-carious cervical defects belong to the non-carious diseases of the hard tissues of the teeth, but it is generally accepted that it is a disease caused by many factors [2,3]. The synergistic effect of acid, wear and occlusal stress is the main cause and mechanism of neck defect. In an acidic environment with a pH below 5.5, the hydroxylapatite in the enamel can be broken down and demineralized, while the organic matrix in the dentin is vulnerable to proteolytic enzymes, if demineralization is accompanied by mechanical wear of enamel and dentin, the wear is accelerated, and the fatigue micro-fissure caused by upper and lower teeth occlusion is also concentrated in the tooth neck, resulting in the loss of hard tissue in the tooth neck. Among them, occlusal force is the most important factor causing neck defect.

Through the finite element analysis of the stress distribution of the first molars restored with different materials under different loading modes, Chen Binwen et al. [4] found that the neck area was the stress concentration area and the non-axial force in the occlusal force, is the most important cause of neck defects. Selma[5] also found that the measured stress of periodontal ligament under axial load is about three times as much as that under axial load under oblique load, the calculated stress of alveolar bone under axial load is almost 10 times of that under axial load. Therefore, it is proved that the occlusal force, especially the paraxial force, is the main cause of the stress in the neck of the teeth, and the highest stress value is near the neck of the teeth, the reasons are consistent.

Root morphology also plays an important role in stress distribution. It has been found[6] that when the maxillary premolars are double roots and the defect depth is 2.5 mm, combined with oblique loading, high stress concentration in the inside of the lesion and at the root bifurcation can be promoted, resulting in high strain level in the neck region, it may be due to the smaller surface area near the root bifurcation caused by neck narrowing in double premolars compared with single teeth. Once the defect is formed, even shallower to 0.5 mm, it is facilitated by a concentration of stress around the neck and a gradual increase in stress as the defect depth increases [7] . At the same time in the process of cervical defect lesions, with the age of patients, alveolar ridge height gradually decreased, force in the promotion of defect progression in the role of more and more important [8].

3. Application of Finite Element Method in Different Restoration of Non-Carious Cervical Defect.

The etiology of non-carious cervical defects is complex, so the treatment should be started from many aspects, such as guiding the patients to correct, oral hygiene practices to prevent its occurrence; desensitization treatment of teeth with sensitive symptoms; different restoration methods according to the degree of defects, mild or moderate use of composite resin or glass ionomer direct restoration, after root canal therapy, the pulp was restored with full crown, post combined crown and post combined resin.

3.1. Direct Filling

Direct filling is often used when the non-carious cervical defect does not involve the dental pulp and the scope is small. The stress distribution can be changed by the presence of the restoration, so the suitable restoration material should be selected to reduce the stress concentration. The main materials used to fill neck defects are Glass ionomer cement and composite resins. For the elderly, [9] glass ionomer cement has the advantages of fluoride release and easy operation, which makes it convenient for clinical work. But

from the angle of mechanics, Yiki [l0] Gart thinks that the material with lower elastic modulus will produce higher stress, and the material with similar elastic modulus to tooth tissue will produce lower stress, therefore, it is recommended to use a material similar to the elastic modulus of tooth tissue. The elastic modulus of the composite resin is close to that of dentin, and the deformation of the composite resin is similar to that of tooth tissue.

When the composite resin is used, the interface between the material and the teeth will inevitably leave a small gap. After the restoration, the teeth will bear the occlusal force, which will cause the neck to bend, and then the interface between the teeth and the composite resin will be partly destroyed. It has been found[11] that the displacement of the buccal tip can be as high as 70.15 um under the lateral force after the direct resin filling, and the large displacement of the buccal tip can lead to the destruction of the adhesive interface. At the same time, compared with the vertical load, the oblique load can produce higher stress concentration in the neck region, which shows that different occlusal contact positions can change the stress concentration in the neck region, thus affecting the success rate of repair[12]. Therefore, the restoration should be carried out after the occlusal adjustment to reduce occlusal interference. In the process of clinical preparation, the doctor usually grinds the neck defect round by the turning needle, but this inevitably increases the chance of exposing the dental pulp. In addition, the polymerization shrinkage of composite resin is also a common reason for failure of repair, such as C factor, resin type, etc. .

3.2. Inlay Repair.

Nowadays, with the development of dental restorative materials, there are more and more methods to repair dental defects. Compared with the full crown restoration, the inlay restoration does not need to remove too much tooth tissue, belongs to the category of minimally invasive restoration. Machado [13] believes that the cervical defects should be repaired with an indirect material with similar mechanical properties to the teeth to replace the lost tooth structure so that it can obtain a stress-strain pattern similar to that of the healthy teeth when subjected to axial loads. At the same time, inlay also has the characteristics of high strength, good abrasion resistance and good edge sealing performance, which can restore the adjacent relationship of teeth and the function of occlusion, it has become a new choice for the repair of large supra-gingival neck defects [14] .

Yu Jingwei [15] established a finite element model of the neck defect and the inlay repaired defect, and found that the stress of the neck defect model was mainly concentrated at the base of the defect under vertical load, while the stress of the inlay repaired model was mainly at the tooth neck, the stress concentration near the defect was obviously improved, and the maximum principal stress was obviously decreased after the inlay of different materials was repaired, especially the ceramic inlay was more ideal. This may be due to the fact that ceramics are rigid, rigid materials with high elastic moduli, which deform less under load, thus reducing the transfer of stress in the structure of the remaining teeth; in contrast, resin composites have low elastic moduli, this makes it easier for the occlusal load to transfer to the remaining tooth structure, increasing the chance of tooth breakage [16] . At present, i-PS-e. The internal structure of the Max ceramic inlay is composed of lithium disilicate crystals, which can delay microfissure, and the elastic modulus is close to dentin. It is not easy to cause tooth fracture when used for repairing the neck defect, and can reduce the occurrence of secondary caries [17] .

When inlay was used to repair the non-carious neck defect, the stress distribution was not only influenced by the material itself, but also influenced by the material. Through the finite element analysis of the influence of the different elastic modulus of the base material on the stress distribution of the ceramic inlay restoration, it is found that[18] the base material with elastic modulus of 13.5 gpa and 22 gpa, the lower the elastic modulus is, the higher the stress of inlay is. The lower the elastic modulus is, the higher the stress distribution is. Therefore, in the use of inlay restoration, can not use underlay material, so that inlay and tooth surface direct bonding repair, that is, direct bonding agent, direct contact with the cavity wall, inlay, stress distribution more uniform.

3.3. Full Crown Repair.

The cervical defect is deep to the pulp, and the fracture resistance of the cervical part of the teeth is reduced after the pulp treatment, which leads to the teeth cracking easily and the full crown restoration is often needed. Multiple finite element studies [12,19] have shown by establishing models of deep cervical defects after root canal therapy that complete crown restoration can significantly improve stress concentration in the apical dentin and the remaining tooth tissue of cervical defects, therefore, it is suggested that full crown restoration should be the first choice to protect the fragile tooth tissues. There are also scholars [20] who argue that crown prosthetics, while protecting the residual crown tissue, can easily transfer stress to the root in an environment of oral activity, resulting in root fracture. Therefore, full crown restoration should fully consider the biomechanical properties of the restoration, the tooth tissue to bite the capacity, but also to wear enough space for the crown. Materials with higher elastic modulus, such as cobalt-chromium alloy, can cause higher tensile stress concentration on the crown surface with uneven surface and higher shear stress in the adhesive layer, which is not conducive to crown retention [21] . So it is necessary to choose suitable material with mechanical and physical properties according to clinical conditions.

S erii at [22] restored mandibular second molars with all-ceramic crowns found the highest stress concentration at 3.77 GPA, but the lowest intradental stress value at 1.69 GPA, compared with composite resin direct restorations. It is concluded that ceramic material can be used as a good choice for full crown restoration, because it cannot transfer stress to teeth and prevent crown or root fracture. At present, all-ceramic crowns and porcelain-fused-to-metal crowns are the most commonly used ceramic materials. Abuel ena i n [23], taking periodontal health into consideration, investigated the clinical feasibility of these two materials for mandibular second molars restoration, the results showed that the stress of the two crowns on periodontal ligament and alveolar bone was similar, so it was considered that all-ceramic crowns and PFM crowns could be used for full crown restoration.

3.4. Post Combined with Full Crown Restoration

For the severe neck defect, the large area defect of the tooth tissue in the crown, if the retention of the full crown is not enough, it is better to use the post in root canal combined with the full crown and composite resin to relieve the neck stress

and reduce the risk of tooth fracture. Shen qingying et al. [24] found that after fiber post composite resin restoration, the stress of dentin on the top of cervical defect was 4.1 mpa, and the tensile stress on the defect was significantly reduced, especially, the stress distribution of the tooth tissue at the post tip has no significant effect, which can significantly reduce the risk of apical fracture. Therefore, for the severe neck defects, post restoration can improve the deep neck defects after root canal therapy, the stress distribution of the affected teeth, is a good clinical severe neck defects repair. The greater the difference between the diameter of the root canal and the diameter of the post, the greater the stress concentration on the surface of the post, especially in the upper-middle two-thirds, which can lead to an increased risk of root fracture [25] , therefore, we should choose the appropriate diameter of the root canal

After root canal therapy, the tooth tissue will become brittle and the stress in the tissue will increase because of the loss of the nutrition support of the pulp and blood nerve, prevent root fracture. In a study [26] comparing biological dentin posts and glass fiber posts with stainless steel posts, it was found that stainless steel posts had higher strength and resulted in uneven stress concentration on the surface of the posts, around the posts, dentin and bonding layer, therefore, in order to improve the clinical success rate of crown restoration, we should choose post materials with similar physical properties to dentin. Mem 0N [27] compared with bio-dentin post and fiber post, the results showed that the stress and displacement of bio-dentin post and fiber post were 127 MPA and 0.025 mm respectively, while the stress and displacement of fiber post were 182 MPA and 0.035 mm respectively, it is concluded that the bio-dentin posts are more closely related to the physical compatibility and Biocompatibility of teeth and can prevent stress accumulation during root canal therapy.

Oyar [28] found that if the elastic modulus of post-and-core material is low, and the elastic modulus of the bonding material is high, it can reduce the deformation of residual roots, post-and-core, and binder, and reduce the stress concentration of post-and-core, therefore, the adhesion of post-and-core material can be reduced, the elastic modulus of junction material should not be too low. The thickness of the adhesive is also important for clinical restoration. The thicker the adhesive, the higher the polymerization shrinkage, the lower the fracture strength and bond strength of the post, and the lower the bond strength between dentin and the adhesive. Furthermore, thicker binders tend to create bubbles, which can lead to the formation of weak areas within the bonding material and destroy the integrity of the interface between the effective polymerization of the resin binder and the fiber post, resulting in higher stress concentration, therefore, dentin/fiber make-up adhesion failure [29] . The stress of dentin can be reduced by choosing thinner adhesive, which is close to the elastic modulus of dentin. Therefore, the thinner adhesive layer is usually sought in clinic, and the higher friction between the adhesive and dentin can prevent the displacement after loading. But on the other hand, thin, bonding layer will produce greater stress [30] , so it is important to find the appropriate thickness of bonding layer.

4. Present Situation and Prospect of Finite Element Analysis.

To sum up, the finite element analysis, by means of simplified modeling, can simulate the force on the teeth to the maximum, and explain the cause of the non-carious neck defect, the research of cavity biomechanics has some advantages. However, in the modeling process, materials are assumed to be continuous homogeneous materials, which means that the model can not completely replace the real dental data. In the research of neck defect, most scholars choose static loading and point loading, but the oral cavity is a dynamic masticatory environment, so the finite element analysis can not completely restore the dynamic masticatory environment, it is impossible to show the complicated force on the teeth, and the experimental results will be biased and have some limitations. For the future application of finite element analysis in dentistry, the emphasis should be placed on further accurate modeling.

5. Conclusion

As real as possible to simulate the oral masticatory environment, such as dynamic loading and so on. For the study of neck defects, the periodontal soft tissues with complex nonlinear mechanical properties should be taken into account, and only the finite element analysis should be combined with the real oral conditions, such as nonlinear, viscoelastic, etc., in order to provide more accurate theoretical basis for clinical work.

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