Cavity Dimension Effect on MOD Dental Restoration Filled with Resin Composite – A Finite Element Interface Stress Evaluation

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Abstract

Resin composite has been one of the widely used materials in dental restorations. The polymerization shrinkage of this material is one of the critical defects provoking failures for the restoration. The biomechanical responses resulted from the interface stress between the resin and tooth (generated by the polymerization shrinkage) would be an important issue in determining the success of restoration. The aim of this study was to evaluate the biomechanical effects of cavity dimension in Class II MOD (mesial-occlusal-distal) restoration using finite element analysis. Solid model of a plastic synthetic second premolar was established by the transverse section slices of the plastic tooth. The model was then revised to create a sub-volume in the crown region to represent the resin filled cavity with various cavity dimensions. Resin material properties were applied in the elements within the cavity and shrinkage of these elements was simulated by a negative thermal expansion. The interface normal stress between the resin and tooth structure induced by this resin shrinkage was evaluated. The results shown that a larger cavity dimension is not always generated a greater interface stress. Since a larger cavity could increase the degree of contraction that leads to the interface stress, it also weakens the remaining tooth structure thus reduce the interface stress.

Keywords: Resin composite, Polymerization, Stress, Cavity, Finite element analysis

Introduction

With the advance of material science, the resin composite is now one of the widely used materials in dental restoration especially when esthetic factor is involved. However, the polymerization shrinkage of resin composite during its curing process is one of the most critical defects to apply this material for restoration. In a restored cavity, this shrinkage should provoke contraction stress causing the composite shrinking away from cavity walls and result in interface stress that disrupts the resin-tooth bonding. This would induce postoperative problems such as microleakage, postoperative pain, and tooth wall deformation. Moreover, polymerization shrinkage could lead to the succeeding destruction of the remaining tooth substance.

Distribution of the interface stress due to the volume contraction is correlated with various factors, such as cavity configuration, resin placement techniques, amount of resin used and the shrinkage rate of the resin itself. Numerous researches were carried to overcome the problems induced by this shrinkage effect. Stansbury [1] and Eick [2] changed the formula of resin composite to reduce the volume shrinkage amount during the polymerization phase. Goracci [3] proposed to use a low-intensity light to delay the hardening process so that there is more time to relief the stress by the gel status of the resin. Lutz [4] had suggested using incremental filling technique within a fix sized cavity to place less composite each time to reduce the interface stress. However, this technique was questioned by Versluis [5]. In the two dimensional finite element study by Versluis, it demonstrated that using an incremental filling approach was not necessary increasing the volume of resin packed within a cavity. Because during the partial filling process, the shrinkage of resin, even is just a portion of the required resin, would deform the cavity wall hence reduce the cavity dimension need further to be filled. Feilzer [6] used C factor (a ratio of bounded surface area over free surface area of the cavity) to explain the relationship between interface stress and cavity geometry. In the study of Lin [7, 8], it was suggested that the debonding of the

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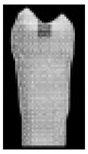
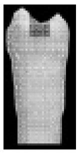
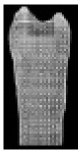
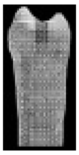
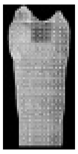
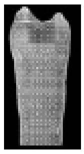
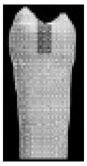
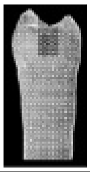
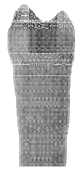
Table 1. The nine evaluated cavity dimensions with depth from 2 to 4 mm and width from 2 to 4 mm at an 1 mm interval respectively.

Cavity Dimension	D=2mm	D=3mm	D=4mm
W=2mm			
W=3mm			
W=4mm			

resin-tooth interface was the primary factor causing the tooth fracture after restoration. Once the interface is debonding, the geometric shape of the Class II MOD (mesial-occlusal-distal) cavity plays an important role in preventing the tooth fracture.

Even with these many researches on resin restoration, the guideline for resin filling is still unclear and sometime conflict suggestions existed. It is therefore necessary to investigate the most fundamental mechanism of the biomechanical behavior of resin restoration. The aim of this study was to investigate the biomechanical influence of cavity dimension on the interface stress for Class II MOD cavity. More specifically, finite element analysis was employed to evaluate the developed interface stress on cavity wall due to the shrinkage of restored resin. The investigated parameter was the dimension of the MOD cavity. The hypothesis was that the larger the cavity dimension, the amount of resin employed would be more which induced a higher interface stress between the resin and the tooth.

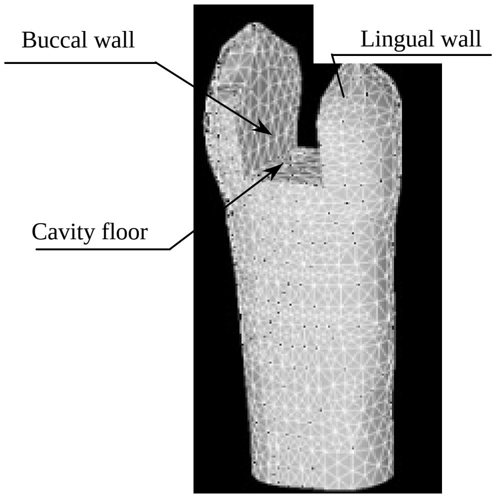


Figure 1. The mesh model of the premolar with cavity preparation to indicate the three stress evaluated surfaces

Material and Method

To establish the finite element mesh model, a plastic synthetic second premolar was used. This plastic tooth was embedded and sectioned (0.8mm interval at the crown region, and 1mm interval for the rest portion) to obtain its cross-sectional profiles. These profiles were then stacked in three dimensional coordinate system within the ANSYS (Swanson Analysis Inc., Huston, Pa, USA) finite element package to generate a solid model of the premolar. The investigated cavity widths were 2mm, 3mm, and 4mm, combined with the cavity depths at 2mm, 3mm, and 4mm. The measurement baseline of the above cavity dimensions was at the central fossa of the premolar. In total, there were nine models as listed in Table 1. To prevent the influence by different element sizes among various models, all these nine mesh models were generated with the same solid model. The largest cavity (4x4 mm) was generated by dividing the tooth crown volume into two sub-volume represented the tooth and cavity respectively. Within the cavity volume, it was further divided into several sub-volume to represent the other eight cavity dimensions. The whole solid model was then meshed with 10-node tetrahedral element within ANSYS. The mesh models of various cavity dimensions were created by assigning different material properties (tooth or resin) for various sub-volume within the solid model.

Because there is only one material in the synthetic tooth, the enamel and dentin could not be established respectively within the premolar model. The material employed for the tooth structure was dentin with an elastic modulus of 18Gpa and Poisson’s ratio of 0.31. The resin properties were assigned with the elastic modulus of 10.3 Gpa and Poisson’s ratio of 0.38. All materials were assumed to be linear and homogeneous.

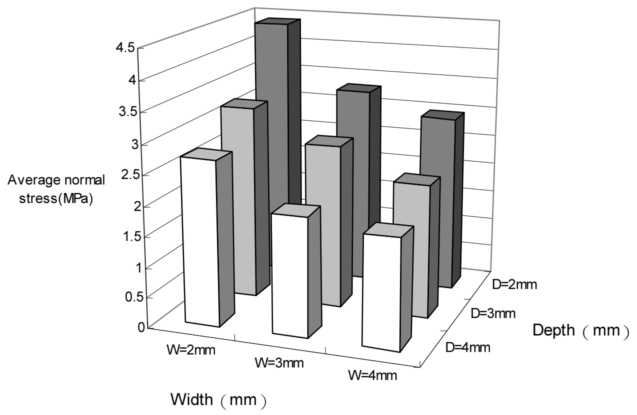


Figure 2. The averaged normal stress on buccal wall

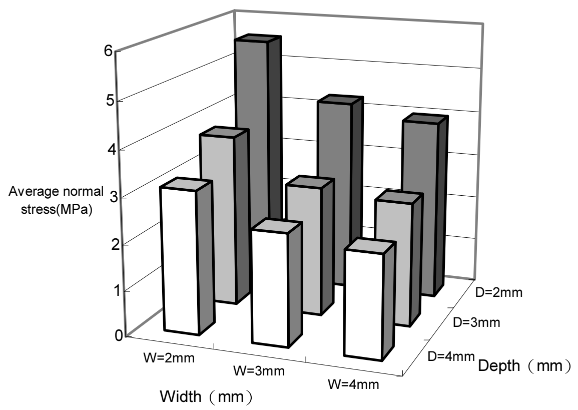


Figure 3. The averaged normal stress on lingual wall

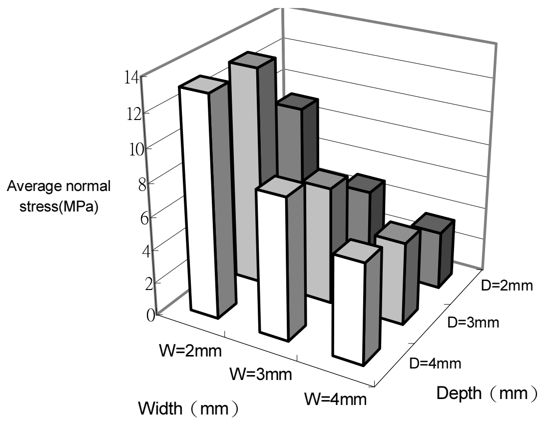


Figure 4. The averaged normal stress on cavity floor

The boundary condition of the tooth was assigned by fixing all the degree of freedoms of the nodes on the bottom (root end) surface. Since the region of interesting of this study was at the crown region, the constraints at the root end should not have too much influence over the crown region. To simulate the polymerization shrinkage effect, the thermal expansion (or shrinkage) approach of the ANSYS modulus was used. The linear thermal expansion coefficient was set at 0.0014 for the resin material. By assigning one degree drop in

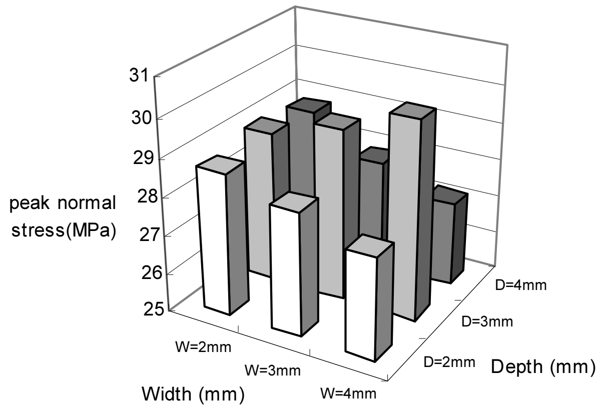


Figure 5. The peak normal stress on the interfaces of the nine models

the temperature of resin, the resin volume would shrink and generate interface stress on the cavity wall due to the constraints of the tooth structure.

Results

The interface normal stress (which should have the dominate effect in debonding the interface) was used as the index to evaluate the cavity dimension effect. The averaged interface normal stress on the cavity's buccal and lingual walls as well as on the cavity floor was evaluated to examine the effects of cavity depths and widths. Figure 1 shows the mesh model of the premolar with cavity preparation to demonstrate the three walls. Figures 2 to 4 shows the averaged normal stress values of the nine models. From figures 2 and 3, two observations could be obtained. Firstly, the interface responses were similar for the buccal and lingual walls with the higher averaged interface normal stress occurred on the lingual wall which was due to its smaller area (compared to the buccal wall). Secondly, contradicted to the hypothesis, the interface stresses did not increase as the cavity dimension enlarged. As a matter of fact, the interface stress decreased as the dimensions of both the cavity width and depth increased. On the cavity floor, the averaged interface normal stress decreased as the width of the cavity enlarged similar to that on the buccal and lingual walls. At the depth dimension, under the same cavity width, the 2mm depth models did hold a smaller interface stress, however, the interface stresses of the 3mm depth models were greater than those of the corresponding 4mm models though the differences were insignificant.

Further evaluated the peak interface normal stresses of these nine models, these peak interface stresses did not demonstrate a clear relationship when the cavity dimensions (both width and depth) changed. As shown in Figure 5, under the same cavity width, the 3mm depth models possessed the highest interface stress while this 3mm depth was neither the deepest (4mm) nor the shallowest (2mm) cavity. For the width factor, the interface stress decreased as the cavity width increased in the 2mm and 4mm depth models. But in the 3mm depth models, the interface stress increased as the cavity width increased.

Table 2. The stress distribution of the three blocks fixed on the exterior surfaces of the two side walls and shrink at the central volume. It is clear to identify that the averaged interface normal stress increased as the shrink volume enlarged.

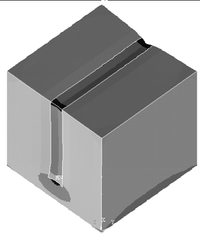
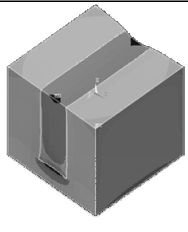
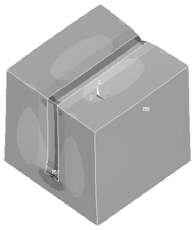
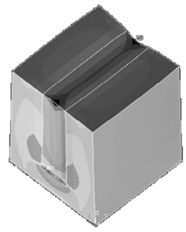
The stress distributions			
Averaged Interface Normal Stress (Mpa)	82.6	121.8	174.2

Table 3. The stress distribution of the three blocks without fixing on the exterior surfaces of the two side walls and shrink at the central volume. It is clear to observe that the two side walls deformed toward the center and the averaged interface normal stress does not always increase as the shrink volume enlarged.

The stress distributions			
Averaged Interface Normal Stress (Mpa)	24.6	27.8	23.1

Discussion and Conclusion

The general idea about the development of interface stress between resin and dental substrate is that the polymerization of a large amount of resin composite would generate higher volume of shrinkage thus higher interface contraction stress. But the simulated outcomes in this study demonstrated anything but the hypothesis of this study. What this indicated was that in preparing the cavity for resin restoration, an over sized cavity might not be a bad choice in view of interface debonding. To exploit the underlying mechanical principle of this phenomenon, it is necessary to examine the interface stress development due to volume shrinkage more carefully. When volume shrinkage occurred, if there is not any obstacle to prevent the shrinkage then no contraction stress would develop within the volume. This is similar to the thermal expansion. If an object were allowed to expand freely as the temperature increased, there would not have any thermal stress developed within the object. This is to say that the development of interface (or contraction) stress needs two components, a region under shrinkage and another contact region to stop (or at least to reduce) the shrinkage. In this investigated resin restoration structure, the shrinkage region would be the cavity while the region to reduce the shrinkage is the tooth structure. For a large cavity, the shrinkage region is enlarged thus increasing the interface stress. Meanwhile, this large cavity would also weaken the tooth structure thus increase its ability to deform with the bonded composite. The interface stress resulted from the shrinkage is a balance of these two factors, the cavity dimension and the stiffness of remaining tooth structure. This explained why the interface stress did not increase as the cavity dimension enlarged.

To confirm the above argument, a simplified block model was developed (Table 2 and 3). In the block central, a sub-volume was shrunk as in the resin cavity. However, to compensate for the lost structure stiffness as the shrink sub-volume enlarged, the exterior surfaces of the side walls were fixed by the boundary constraints. As shown in Table 2, the interface normal stress increased as the shrink sub-volume increased which matched the hypothesis of this study. Nevertheless, if the two exterior surfaces were not fixed (as in the tooth model of this study), the two side walls would deform toward the center sub-volume and the interface stress was not necessary increased as the shrink sub-volume enlarged which consisted with the simulated outcomes of this study (Table 3).

Before presenting the conclusion of this study, it is necessary to note that the established FE simulation models have several limitations, such as: without enamel material, simplification of the cavity configuration, and one-step-shrinkage of the resin (all resin shrink and hardening at the same time). Therefore, the outcomes of the simulation should be treated as mechanism investigation rather than clinical guideline. To conclude, using resin for dental Class II MOD restoration, a larger cavity dimension is not necessary provoking greater risk in interface debonding. An optimal cavity dimension might exist for each individual tooth in view of preventing interface debonding.

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References

[1] J.W. Stansbury, "Synthesis and evaluation of novel multifunctional oligomers for dentistry", *Journal of Dental Research*, 71: 434-437, 1992.

[2] J.D. Eick, T.J. Byerley, R.P. Chappell, G.R. Chen, C.Q. Bowles, and C.C. Chappelow, "Properties of expanding SOC/epoxy copolymers for dental use in dental composites", *Dental Materials*, 9: 123-127, 1993.

[3] G. Goracci, G. Mori, and L.S. de Martinis, "Curing light intensity and marginal leakage of resin composite restoration", *Quintessence International*, 27: 355-362, 1996.

[4] F. Lutz, I. Krejci, and T.R. Olderburg, "Elimination of polymerization stresses at the margins of posterior composite resin restorations: a new restoration technique", *Quintessence International*, 17: 777-784, 1986.

[5] A. Versluis, W.H. Douglas, M. Cross, and R.L. Sakaguchi, "Does an incremental filling technique reduce polymerization shrinkage stresses", *Journal of Dental Research*, 75: 871-878, 1996.

[6] A.J. Feilzer, A.J. de Gee and C.L. Davidson, "Setting stress in composite resin in relation to configuration of the restoration", *Journal of Dental Research* 66: 1636-1639, 1987.

[7] C.L. Lin, C.H. Chang, and C.C. Ko, "Multifactorial Analysis of An MOD Restored Human Premolar Using Auto-Mesh Finite Element Approach", *Journal of Oral Rehabilitation*, 28: 576-585, 2001.

[8] C.L. Lin, C.H. Chang, C.H. Wang, C.C. Ko and H.E. Lee, "Numerical Investigation of the Factors Affecting Interfacial Stresses in a MOD Restored Tooth By Auto-Meshed Finite Element Method", *Journal of Oral Rehabilitation*, 28: 517-525, 2001.