The Effect of Cavity Shape and Hybrid Layer on the Stress Distribution of Cervical Composite Restorations

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ABSTRACT

Objectives: The aim of this finite elemental stress analysis study was to evaluate the effect of cavity shape and hybrid layer on the stress distribution of the mandibular premolar tooth under occlusal loading.

Methods: The mandibular premolar tooth was selected as the model based on the anatomical measurements suggested by Wheeler. Four different mathematical models were evaluated: 1) a saucer-shaped non-carious cervical lesion restored with a composite without a hybrid layer, 2) a saucer-shaped non-carious cervical lesion restored with a composite with a hybrid layer, 3) a wedge-shaped non-carious cervical lesion restored with a composite without a hybrid layer, and 4) a wedge-shaped non-carious cervical lesion restored with a composite with a hybrid layer. A 200 N force was applied from the buccal tubercule and central fossa of the premolar tooth. The findings were drawn by the SAPLOT program.

Results: In models 2 and 4, the output showed that a hybrid layer acts as a stress absorber. Additionally, when the cavity shape was changed, the stress distribution was very different.

Conclusions: Cavity shape and hybrid layer play an important role in stress distribution in cervical restorations. (Eur J Dent 2011;5:180-185)

Key words: Non-carious cervical lesion; Hybrid layer; Stress distribution; Finite element analysis; Premolar tooth.

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INTRODUCTION

Non-carious cervical lesions attributed to erosion, abrasion, and occlusal loading; usually take the shape of a wedge or a saucer.[1-3] In wedge-shaped lesions, there is a sharp line angle at the axial wall. In saucer-shaped lesions, is enlarged occlusally relative to the wedge and there is no sharp line.[4,5] Radenz and colleagues[6] reported that angular wedge-shaped defects (which are probably related to occlusal loading) were seen more frequently than the rounded variety (which are probably related to erosion) and that defects were seen more commonly on incisors and premolars. A cervical lesion changes the distribution of stress within a tooth. Grippo[7] suggested that if the lesion were left unrestored, the stress concentration caused by the cervical lesion would facilitate further deterioration of tooth structure. He hypothesized that cervical restoration decreases the concentration of stress and the progression of the lesion.[7] Therefore, restoration of non-carious cervical lesions is important. Non-carious cervical lesions are restored mostly with resin-based esthetic restorative materials like composite, resin-based glass ionomer.[8] With composite resin restorations, to obtain proper bonding, forming a hybrid layer in the resin dentin interface is essential.[9-11] In addition, many researchers have asserted that the hybrid zone might act as a stress absorber in the dentin bonding procedures because of its elasticity structure.[12-15] A hybrid layer is very different from the original tooth structure chemically and physically because it has been partially demineralized and then infiltrated with resin. The resulting structure is neither dentin nor adhesive but a hybrid of the two.[16]

The aim of this finite element stress analysis study was to evaluate the effect of hybrid layer on the distribution and the amount of stress formed under occlusal loading in a premolar tooth with wedge-shaped and saucer-shaped cervical lesions, restored with composite. The null hypothesis of this study was that cavity shape and hybrid layer did not affect the stress distribution of the non-carious cervical restorations.

MATERIALS AND METHODS

In this study, a three-dimensional finite element model simulating the cross-section of a mandibular premolar tooth was used. The mathematical models were based on the anatomical measurements suggested by Wheeler.[17] The model included simulations of cortical bone, spongiose bone, periodontal membrane, enamel, dentin, hybrid composite, the adhesive layer, a hybrid layer, and pulp tissue. Their elastic properties, were determined from the literature. The thickness of the composite restorations was 2 mm, the width of the adhesive layer was 30 µm, and the width of the hybrid layer was 1.5 µm.[18] Each mathematical model was composed of 966 nodes and 726 solid elements. The analysis was performed using a computer (Sony Vaio UGN-FZ320EIB 1.66 GHz Intel Core 2 Duo) and the SAP 2000 structural program (Computer Structures Inc. Berkley, CA).

Two different mathematical models including saucer-shaped and wedge-shaped non-carious cervical lesions were created (Figures 1 and 2).

Four different restoration types were evaluated using these models:

Model A: Saucer-shaped non-carious cervical lesion restored with a composite resin without a hybrid layer.

Model B: Saucer-shaped non-carious cervical lesion restored with a composite resin with a hybrid layer.

Model C: Wedge-shaped non-carious cervical lesion restored with a composite resin without a hybrid layer.

Model D: Wedge-shaped non-carious cervical lesion restored with a composite resin with a hybrid layer.

All models were loaded from central fossa and buccal tubercule with a total 200 N force (100 N per each point) (Figures 1 and 2).[17,19] The final elements on the X and Y axis for each model were assumed to be fixed based on boundary conditions. Stress distribution and amounts have been calculated using von Mises stress criteria.[20] The outputs were transferred to the SAPLOT program to display the resulting shear stress values.

RESULTS

Figure 3 (Model A) shows a lower premolar tooth model with a saucer-shaped non-carious cervical lesion restored with a composite resin. In this model, a hybrid layer was not included. When 200 N was loaded on the buccal tubercule and central fossa (100 N for each), more stress accumulation was observed on the gingival margin of the composite restoration. The gingival margin of the composite restoration was seen in yellow (38-46 MPa), and the occlusal margin of the composite was seen in brown (23-31 MPa). When the composite restoration was evaluated mesio-distally, the gingival margin was the most intense surface, and this intensity decreased the occlusal margin of the composite. And when the composite restoration was evaluated bucco-lingually, the stress intensity decreased toward the lingual direction. Figure 4 (Model B) depicts the stress distribution of a lower premolar tooth model with a saucer-shaped non-carious cervical lesion restored with a composite resin. In this model, a hybrid layer was included, and the stress distribution decreased on all composite surfaces (gingival, axial, and occlusal). The gingival margin of the composite restoration was seen in dark yellow (31-38 MPa), and occlusal margin of the composite restoration was seen in red (8-15 MPa) (Figure 4). Figure 5 (Model C) shows a lower premolar tooth model with a wedge-shaped non-carious cervical lesion restored with a composite resin. As with Model A this model did not include a hybrid layer.

The gingival margin of the composite restoration was the most intense surface, seen in light yellow (46-54 MPa), and the occlusal margin of the restoration was seen in brown (23-31 MPa).

Figure 6 (Model D) illustrates the stress distribution of a lower premolar tooth model with a wedge-shaped non-carious cervical lesion restored with a composite resin. This model included a hybrid layer, as did Model B. When a hybrid layer was added, the stress distribution decreased. In this model, the gingival margin of the restoration was seen in dark yellow (31-38 MPa), and occlusal margin of the restoration was seen in brown (23-31 MPa).

DISCUSSION

Non-carious cervical lesions represent a difficult challenge to the dental profession because they are common, because it is likely their prevalence will increase as the nation's population ages, and because the position of these lesions makes it difficult to provide a long-lasting restoration. These lesions were restored with resin-based esthetic restorative materials like composite, resin-based glass ionomer. Researchers report-

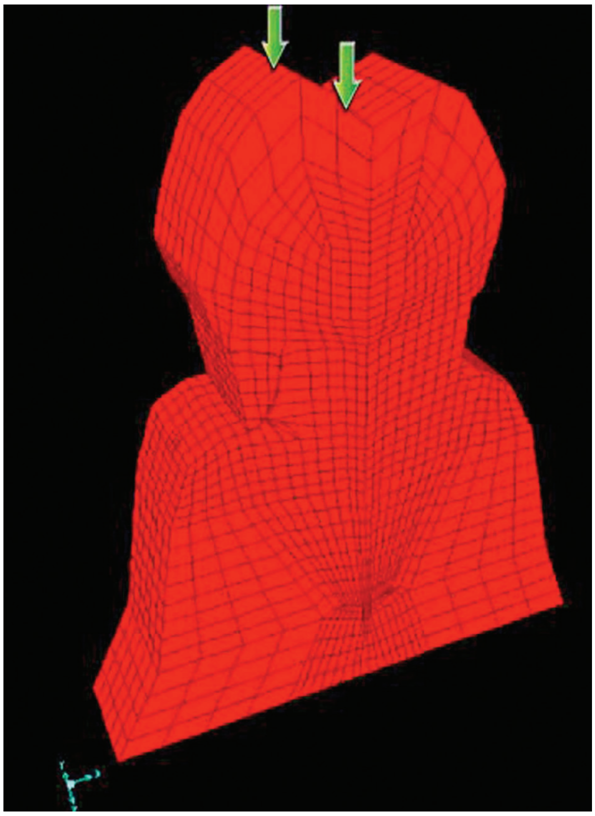

Figure 1. A mathematical model including a wedge-shaped non-carious cervical lesion loaded with 200 N is seen.

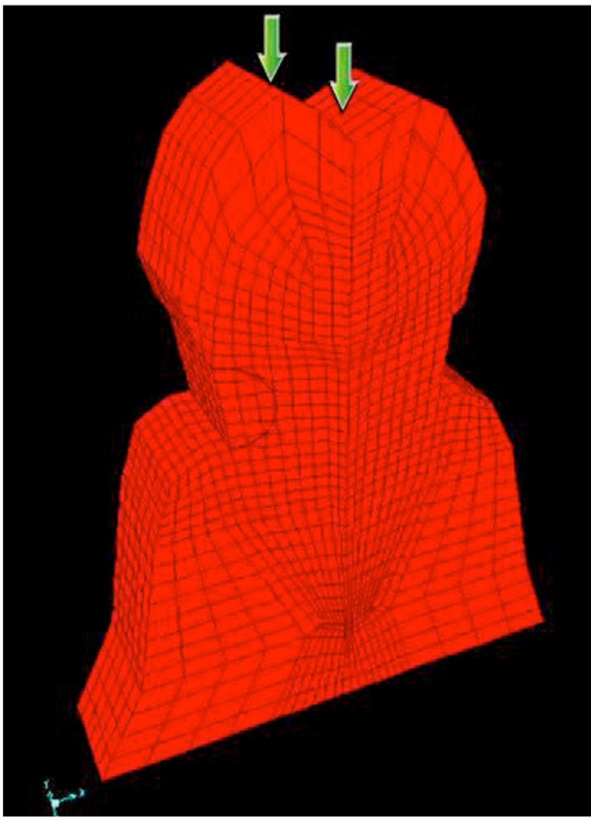

Figure 2. A mathematical model including a saucer-shaped non-carious cervical lesion loaded with 200 N is seen.

ed unfavorable results regarding the longevity of cervical restorations.[21-25] Secondary caries is common around this type of restoration. The ineffectiveness of cervical restorations is caused by the difficulties in bonding sclerotic dentin.[26,27] In addition to sclerotic dentin; stressful occlusions influence the retentive failure rates. Van Meerbeek et al[28] confirmed that stress concentration at the cervical region is responsible for not only the development of cervical lesions, but also restoration retention failure. The stress created by occlusal loadings is not only distributed in structures such as enamel and dentin, but also concentrated in areas such as the composite and adhesive layers.[4] It was reported that, to reduce this stress, in addition to the utilization of flexible restorative materials, applying flexible adhesives to the resin dentin bonding layer could be beneficial.[29] Van Meerbeek et al[30] reported that the elastic structure of the hybrid layer formed by collagen tissue and supported by resin can tolerate the stress generated by occlusal loadings. The shaping of hybridization is the most important mechanism of bonding. During hybridization, the mineral phase of hard tissue is dissolved to expose the collagen matrix, and this matrix is then infiltrated with resin monomer to intentionally change the physical and chemical properties of the hard tissue.[31]

Belli et al[14] analyzed the effect of hybrid layer on the amount and distribution of stress generated by occlusal forces in premolar teeth restored with a composite and ceramic inlay and concluded that the hybrid layer reduced the stress distribution in restorative materials.

Ausiello et al[12,13] analyzed the effect of hybrid layer in Class II cavities with FEM in two different studies and reported that a hybrid layer served as a cushion to both polymerization shrinking and the stress generated by occlusal forces between restorative material and dental tissue. Different from previous studies, this study analyzed the effect of hybrid layer on the stress distribution of non-carious cervical restorations and determined that it absorbed the stress intensity in the cervical

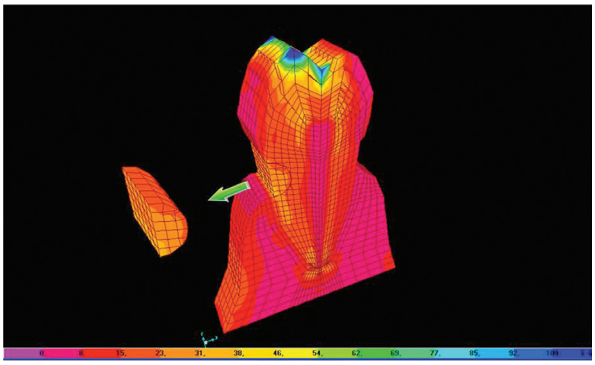

Figure 3. A saucer-shaped non-carious cervical lesion restored with a composite resin without a hybrid layer. When stress distribution was compared, the gingival margin of the composite restoration was the most intense surface (38-46 MPa).

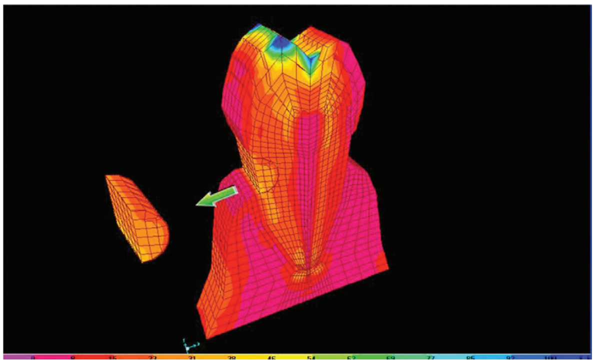

Figure 4. A saucer-shaped non-carious cervical lesion restored with a composite resin with a hybrid layer. When a hybrid layer was added, stress intensity decreased in composite surfaces. The gingival margin of the composite restoration was seen in dark yellow (31-38 MPa).

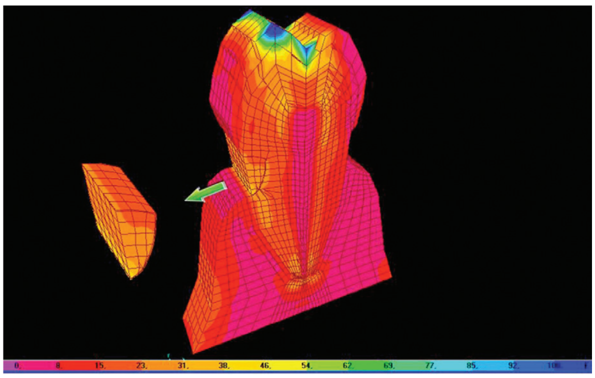

Figure 5. A wedge-shaped non-carious cervical lesion restored with a composite resin without a hybrid layer. The stress distribution was very different from that in saurcer-shaped lesions. The gingival margin of the composite restoration was seen in light yellow (46-54 MPa).

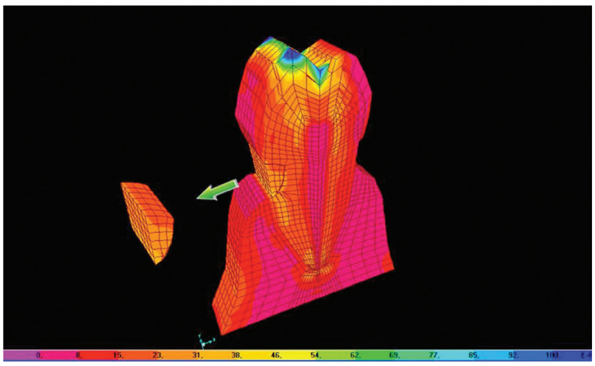

Figure 6. A wedge-shaped non-carious cervical lesion restored with a composite resin with a hybrid layer. The stress intensity decreased in composite surfaces when a hybrid layer was added. The gingival margin of the composite restoration was seen in dark yellow (31-38 MPa).

region induced by occlusal forces. In addition that stress distribution within a mandibular premolar was affected by cavity shape, too. The wedge-shape lesion had a sharp angle at the axial wall. As a result, the stress distribution at the axial wall was higher than in the saucer-shaped lesion. Similar to our results, Kuroe and collegues[5] confirmed that differences in lesion shape influenced the interfacial stress between a restoration and tooth structure. From the etiology of cervical abfraction[32] or stress induced lesions,[33] a tooth flexure concept is derived that also may affect the retention of Class V adhesive restorations.[1,24,34,35] The concentration of compressive and tensile stress at the cervical area induced by eccentric or heavy centric occlusal forces may progressively dislodge and eventually debond resin restorations.[34,35] Elastic buffers underneath composite restorations may also better withstand shocks induced by occlusal loading.[29] The results of this study showed that the hybrid layer behaved as an elastic buffer and decreased the stress concentration in the cervical region induced by occlusal forces.

CONCLUSIONS

Within the limitations of this FEM study, the following was concluded:

- The hybrid layer plays an important role in stress distribution. It absorbed the stress created due to the occlusal loading in cervical restorations.
- Cavity shape affected stress distribution in non-carious cervical restorations. The stress distribution of, saucer-shaped non-carious cervical lesions were shown to be more advantageous than wedge-shaped lesions.

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