치의과학석사 학위논문

Comparison in stress distribution of different base materials and thicknesses in MOD class II direct composite resin restoration: A 3D finite element study

Class II MOD 직접 복합 레진 수복 시 기저재의 종류와 두께에 따른 응력 분포의 비교: 삼차원 유한 요소 연구

2020 년 8 월

서울대학교 대학원

치의과학과 치과보존학 전공

정 민 관

Abstract

Comparison in stress distribution of different base materials and thicknesses in MOD class II direct composite resin restoration: A 3D finite element study

Min-Kwan Jung, B.D.S.
Program in Conservative Dentistry
Department of Dental Science
Graduate School, Seoul National University
(Directed by Prof. Deog-Gyu Seo, D.D.S., Ph.D.)

1. Purpose
The purpose of this study was to investigate and compare the stress distribution of different base materials and thicknesses in posterior direct MOD class II resin restoration.

2. Material and methods
Nine 3D models of teeth obtained from CBCT scan data were fabricated and analyzed through 3D CAD software (ABAQUS CAE 2016, Dassault systems, Velizy-Villacoublay, France). The experimental groups of 3D models were categorized as follows:
Control: Sound tooth
Group A: Composite resin without base material
Group B: Lithium disilicate with resin cement layer
Group C-tn: Composite resin with glass ionomer cement base 0.5

mm
Group C−tk: Composite resin with glass ionomer cement base 1.0 mm
Group D−tn: Composite resin with low−viscosity resin base 0.5 mm
Group D−tk: Composite resin with low−viscosity resin base 1.0 mm
Group E−tn: Composite resin with tricalcium silicate cement base 0.5 mm
Group E−tk: Composite resin with tricalcium silicate cement base 1.0 mm
Group C, D, E had multi−layer construction consisted of adhesive layer, base and composite resin. Then these groups were further divided into two sub−groups: thin (tn) and thick (tk). Stress distribution of all groups were compared and analyzed by visualizing maximum principal stress of each model after simulation of vertical loading with 600 N on occlusal surface. Polymerization shrinkage effect on resin−based materials was applied in prior to vertical loading.

3. Results
Sound tooth showed lowest stress value and its stress propagation was confined on outer enamel surfaces only. Group A showed highest stress distribution along interfaces between tooth and restoration with increased failure risk on marginal area. In contrast, Group B showed the lowest maximum stress value among all groups although the stress was concentrated on resin cement layer. Group C, D, E both in thin and thick subgroups showed reduced stress level compared to Group A. However, differences in stress distribution between base materials and base thicknesses of 0.5 mm and 1.0 mm were not significant.

4. Conclusion
Marginal stress caused by polymerization shrinkage of composite resin was reduced by presence of GIC, low−viscosity resin and tricalcium silicate cement bases in class II MOD direct composite resin. However, influence of different base materials and thicknesses

of 0.5 mm and 1.0 mm on stress distribution of tooth and composite resin was not observed.

....

Keywords: 3-Dimensional finite element analysis, Base material, Class II MOD cavity, Polymerization shrinkage, Stress distribution

Student Number: 2017-29948

Contents

Comparison in stress distribution of different base materials and thicknesses in MOD class II direct composite resin restoration: A 3D finite element study

Min-Kwan Jung, B.D.S.
Program in Conservative Dentistry
Department of Dental Science
Graduate School, Seoul National University
(Directed by Prof. Deog-Gyu Seo, D.D.S., Ph.D.)

I. Introduction

Resin based dental composite materials are commonly used for class I and class II adhesive restorations, due to its esthetic, physical properties and availability.[1-3] Despite of its advantages, it has been a critical concern that a dimensional change during polymerization process causes stress within the material and its interface between the tooth structure as the resin composite bonds to tooth structure through micromechanical interlocking.[4] The internal stress generated by polymerization shrinkage may be transferred to bonded tooth that leads to enamel cracks, cuspal deflection and deformation of tooth walls.[5]

In order to challenge negative effects of polymerization shrinkage in clinical setting, sandwich technique has been suggested.[6] This method is performed by placing intermediate base or liner underneath resin-based composite on the cavity floor. Underlying base or liner material may act as stress absorbing layer and reduce internal stress from shrinkage by replacing the volume of resin composite mass.[7]

Different types of base material are available for sandwich technique and are normally indicated by its lower shrinkage rate and enough strength to withstand the forces of shrinkage and occlusion.[8] Glass ionomer cement (GIC) is well-known for its biocompatibility, and chemical adhesion ability which do not shrink during setting.[9-10] Use of resin-based materials with lower elastic modulus and lower viscosity such as flowable resins also have been suggested as it increases the strain capacity and reduces the stress on the adhesive interface.[11-12] Tricalcium-silicate based cement has gained popularity in recent years for its high fracture strength, chemical stability and biocompatibility.[13] The use of tricalcium-silicate based cement was recommended as an alternative choice for base material under posterior direct resin restorations.[14]

Choosing base material may require thorough consideration in order to reduce adverse effects of polymerization shrinkage of resin composites. Despite many choices are available in base materials for direct resin restoration, selecting appropriate base material and its thickness is still a concern. Although base materials with lower elastic modulus were suggested to relieve polymerization shrinkage effects due to its ability to stretch[15], in vitro studies showed contradictory results on influence of different elastic modulus of base materials.[16-19] Moreover, there is lack of scientific evidence on influence of different thicknesses of base material on polymerization shrinkage stress.[20] Biomechanical investigation is needed to analyze and compare the influence of different base materials and thicknesses on the polymerization shrinkage effects of composite resin in order to suggest ideal material and thickness in clinical practice.

Three-dimensional finite element analysis (3D FEA) has been effective tool to investigate the biomechanical behavior that is employed to evaluate the stress distribution in the tooth and dental materials.[21] Several studies conducted through FEA method were able to analyze the residual stress caused by polymerization shrinkage in direct resin restorations.[22-24] The influence of different base materials in direct composite resin restoration under functional loading was also investigated by previous FEA studies as well.[25-27]

However, none of these FEA studies considered the effect of different base thicknesses and base material with high elastic modulus as tricalcium silicate cement.

The aim of the present study was to investigate and compare the effects of different base materials and thicknesses in stress distribution of tooth restored by direct Class II MOD composite resin using a 3D FEA method.

II. Material and methods

A 3D model of the upper left second premolar, used in previous 3D FEA investigation[28] was considered in this study. A CBCT image of a normal Korean male adult maxilla was cut into a 0.25 mm thickness to obtain two-dimensional images. The obtained images were used to reconstruct three-dimensional maxilla model using Mimics program. (Mimics Research v19.0, Materialise, Provincie Vlaams-Brabant, Belgium). Single tooth model was constructed by extracting the portion corresponding to the upper left second premolar region. The external contours of the tooth model as well as internal enamel and dentine contours were outlined by using SolidWorks software (SolidWorks, Waltham, MA, USA).

The designs of inlay preparation of tooth, bonding layers and base materials were constructed via derived tools from SolidWorks software and are illustrated in Figs. 1-4.

The bucco-lingual dimension of the tooth model was 9.55 mm with mesio-distal dimension of 7.75 mm. The distance between buccal and lingual cusp tips of the sound tooth model was measured (7.30 mm) and its middle point was set as center line of the inlay preparation design. The width of inlay preparation was considered as the half of measured distance between buccal and lingual cusp tips which is 3.15 mm. The width of mesial and distal proximal box was set as 4.87 mm which is two third of distance between buccal and lingual cusp tips. The height of axial wall was set as 1.00 mm and the pulpal floor was 2.50 mm below the central fossa. The width of gingival floor was set as 1.30 mm. A 95 degree of cavity-margin-angles with rounded bevel on axio-pulpal line angles was considered in the design.

Resin composite models are constructed according to the tooth preparation design. Base materials are designed to cover pulpal floor and axial walls of prepared tooth. Base materials in the present study has two different designs according to its thickness which are 0.5 mm and 1.0 mm. Both base designs have same gingival width of 0.5 mm and only differ in pulpal height by 0.5 mm.

The above constructed 3D models of tooth and materials were imported into the FEA software (Abaqus CAE 2016, Dassault systems, Velizy−Villacoublay, France). Eight models of a restored tooth and one sound tooth were created and analyzed to investigate the influence of different base materials and thicknesses in terms of stress distribution. These models with different material combinations were categorized into following groups;

Control: Sound tooth.

Group A: Direct composite resin restoration (CR) without base material.

Group B: Indirect lithium disilicate restoration with resin cement.

Group C−tn: CR with 0.5 mm glass ionomer cement base.

Group C−tk: CR with 1.0 mm glass ionomer cement base.

Group D−tn: CR with 0.5 mm low−viscosity resin base.

Group D−tk: CR with 1.0 mm low−viscosity resin base.

Group E−tn: CR with 0.5 mm tricalcium silicate cement base.

Group E−tk: CR with 1.0 mm tricalcium silicate cement base.

Group C, D, and E had multilayer construction consisted of adhesive layer, base and composite resin. These groups were further divided into two subgroups according to its thickness: thin (0.5 mm) and thick (1.0 mm). All model groups except Group B include adhesive layer underneath CR with 0.07 mm thickness. Group B rather includes resin cement layer with thickness of 0.10 mm.

For each model, the size of the mesh used was minimum 0.05 mm to 0.30 mm in maximum. The number of elements and nodes used in all FEA models are listed in Table 1. Different values of Young's modulus and Poisson's ratio of tissues in tooth and other restorative materials were assumed. The mechanical property data used in the study were based on previous studies[27,29,30] and are summarized in Table 2. The maximum principal stress criterion was considered to analyze the results.

Combined effect of polymerization shrinkage of resin−based materials and occlusal loading was analyzed in terms of stress distribution. The polymerization shrinkage effect was processed in prior to application of occlusal load.

To simulate the effect of polymerization shrinkage for the adhesive layers and resin composite materials, the thermal expansion approach was used. A linear thermal expansion coefficient of 0.01 was assumed. By assigning a one-degree drop in temperature of the resin-based materials, contraction stress was generated at the tooth-restoration interface. The assigned magnitudes of linear shrinkage were 1.0%.

Fabricating of food bolus model was considered to simulate occlusal force. Food bolus has occluding surface that opposes the occlusal surface of the tooth model. The contact area between food bolus and tooth is confined on central area between bucco-lingual cusp tips and mesio-distal ridges which is illustrated in Fig. 5. A 600 N of static vertical force was loaded on occlusal surface of the tooth through the food bolus model to simulate close phase of mastication (Fig. 6).

As the linear static analysis is considered, all the materials were assumed to behave as elastic materials throughout the entire deformation under isotropic characteristics and homogeneity to all directions. A perfect bonding of resin and base materials was assumed.

III. Results

As tooth structure exhibits brittle behavior, the maximum principal stress criterion was considered to assess the damage due to the applied functional loads on the tooth.

The stress distribution of all groups after simulation of combined effects of polymerization shrinkage and occlusal loading of 600 N were displayed in (Figs. 7–11). The polymerization shrinkage effect was processed in prior to occlusal load. Overall, the stress pattern was mainly affected by shrinkage effects of composite resin over effect of occlusal loading of 600 N.

In sound tooth model, the stress was uniformly distributed along enamel with the lowest maximum principal stress value and no critical stress concentration was observed (Fig. 7a). The stress absorbing effect of dentine was displayed in the bucco-lingual cut section (Fig. 9a).

Group A (Composite resin without base) demonstrated highly concentrated stress distribution on both restoration and tooth along with marginal interface especially on marginal angles (Fig. 7b). Internal stress within composite resin material originated from marginal inter-surface was observed (Fig. 9b).

In contrast, Group B (lithium disilicate with resin cement) showed resembling stress distribution on enamel to that of sound tooth (Fig. 7c). A confined stress on resin luting cement was observed both externally and internally (Figs. 7c and 9c). Bucco-lingual cross-sectional view on lithium disilicate showed a moderate level of internal stress on the inferior region extending from pulpal margin.

The stress distribution of Group C, D, and E was demonstrated in Figs. 8 and 10. A detailed view on composite resin in the bucco-lingual sectional view was displayed in Fig 11. A moderate level of stress on the surface of composite resin was observed in all base groups and the stress was intensified near marginal interfaces (Fig. 8). A low range of stress was transferred to the enamel region on marginal angles (Fig. 8). In bucco-lingual sectional view, localized stress concentration along with marginal interfaces within composite resin was displayed in all groups (Figs. 11). Group D-tn and D-tk showed a moderate level of internal stress within low−viscosity resin base (Figs. 8c and d).

In comparison of Group C, D, and E, there was no significant difference observed in stress pattern and magnitude on both tooth structure and composite resin (Figs. 8 and 10). Thin and thick base groups (tn and tk) also showed no significant difference in stress distribution on both tooth and composite resin.

The highest maximum principal stress values of each tooth inter−surface in all groups under combined loading conditions were recorded and compared in the graph (Fig. 13). Each tooth surface was labeled according to the illustration (Fig. 12). Group A showed the highest stress value on all surfaces. Compared to other groups, Group B showed that the value of maximum stress is uniformly distributed along all surfaces with the lowest value in average. Group D−tn and D−tk showed slightly higher average stress value than other groups except for Group A. The difference in stress value between different base thicknesses of Group C, D, and E was not significant.

IV. Discussion

This study investigated the effects of different base materials and thickness under class II MOD direct resin restoration in terms of stress distribution. The result showed that base materials such as GIC, low−viscosity resin, and tricalcium silicate cement under composite resin reduced stress on tooth−restoration interface compared to direct composite resin without base. This finding was supported by previous laboratory studies[17,18] suggesting that the presence of base material in direct resin restoration helps in reducing stress caused by polymerization shrinkage effect of composite resin. The reduction in the volume of resin composite mass and bonded surface area may have reduced the adverse effects of polymerization shrinkage as the shrinkage stress of resin material is affected by its configuration factor and volume.[23,24]

The composite resin restoration without base material (Group A) showed critically concentrated stress along marginal surfaces both on enamel and composite resin. The concentrated stress on a marginal area was caused by internal contraction force on the resin−tooth interface generated by volumetric change of resin composite material. The present result verifies previous studies that the adverse effect of polymerization shrinkage may lead to marginal failure due to its dimensional change and contraction stress.[4,5] It seems that the application of base material could be beneficial when directly restoring class II MOD cavities as it reduces adverse effects from polymerization shrinkage of composite resin.

Group C, D and E (GIC, low−viscosity resin and tricalcium silicate cement bases) showed no significant difference in stress distribution on tooth and composite resin. According to the previous studies,[19,20] base materials with low elastic modulus were suggested to relieve stress caused by polymerization shrinkage of composite resin due to its ability to stretch allowing relaxation of contraction force. However, different elastic modulus of base material in present study did not affect the stress pattern and magnitude of polymerization shrinkage of composite resin. According to the present results, it seems that the influence of different elastic modulus of base materials may be masked by the predominant effect of configuration factor and volumetric dimensional change of composite resin material.

Although Group D (low−viscosity resin base) showed a moderate−range of internal stress within base material due to its shrinkage effect, the stress pattern and magnitude on composite resin was not significantly different to GIC and tricalcium silicate cement which are non−shrinking base materials. This result was in accordance with previous 3D FEA study[27] that have shown that both non−shrinking GIC and shrinking flowable resin base materials did not significantly modify the stress pattern caused by polymerization shrinkage of composite resin. It seems that the low level of stress caused by shrinkage of low−viscosity resin base was covered by shrinkage effect of composite resin as the configuration factor and volumetric shrinkage of low−viscosity resin was significantly less than that of composite resin.

The influence of different base thicknesses was not observed in present result as well. This was in accordance with previous in vitro study that has shown that difference of layer thickness from 0.5 mm to 1.0 mm in both resin−modified GIC and flowable resin bases promoted no significant difference in polymerization contraction force caused by composite resin.[20] The base thickness design used in the present study also only differed in pulpal height by 0.5 mm with fixed gingival width. The volume and bonded surface area of composite resin in thick base groups was not considerably less than in thin base groups regarding the size of inlay cavity of the tooth model.

The stress distribution of tooth restored indirectly by lithium disilicate with resin luting cement was also investigated to compare with direct composite resin. Group B (lithium disilicate) showed lowest level of stress with uniform stress distribution which resembles that of sound tooth. This result was in accordance with a previous 3D FEA research[31] showing that indirect glass−ceramic was superior to direct resin restoration in reducing stress on tooth with class II MOD cavities. This is because lithium disilicate is free from adverse effect of polymerization shrinkage, and it provides high mechanical strength (elastic modulus of 70.0 GPa) which resembles to that of enamel (80.0 GPa) allowing uniform distribution of external forces.[32] However, confined stress on resin luting cement was observed in present result with a low range of internal stress within lithium disilicate superiorly to pulpal floor. This finding supports previous clinical studies[33,34] reporting that the majority of bulk fractures of ceramic were originated from adhesive resin cement interface.

Although the occlusal load of 600 N was applied after the polymerization shrinkage effect in the study, the stress pattern in all groups was not significantly modified by the occlusal loading. This seems to be due to spacious contact area between food bolus and occlusal surface of tooth that the dimension of occlusal contact area affects the stress distribution.[35]

The study assumed the perfect bonding of base materials and composite resin as in FEA investigations [25,27,31] which does not occur in clinical situation. The bonding interface of composite resin and base materials can be affected by several clinical factors as filler contents of composite resin, degree of conversion and water sorption[36,37]. Considering the above multi factors comprehensively with other laboratory[16-20] and clinical studies[1,10,11] may help in understanding the complex behavior of the polymerization shrinkage and the stress.

V. Conclusion

Under limitations of the present study conducted through 3D FEA assuming isotropic linear elastic behavior of materials, it can be concluded as below;

1. The application of base materials including GIC, low-viscosity resin and tricalcium silicate cement reduced the marginal stress caused by polymerization shrinkage of composite resin in class II MOD cavity.
2. The different elastic modulus of base materials did not influence the stress distribution of tooth and composite resin.
3. The thickness difference from 0.5 mm to 1.0 mm in base material did not affect the stress distribution of tooth and composite resin.
4. The tooth indirectly restored by lithium disilicate showed the lowest stress value with uniform stress distribution.

References

1. Heintze SD, Rousson V. Clinical Effectiveness of Direct Class II Restorations – A Meta–Analysis. *J Adhes Dent* 2012;14:407–431.
2. Collins CJ, Bryant RW, Hodge KLV. A clinical evaluation of posterior composite resin restorations: 8–year findings. *J Dent* 1998;26:311–317.
3. Mair LH. Ten–year clinical assessment of three posterior resin composites and two amalgams. *Quintessence Int* 1998;29:483–490.
4. Schneider LFJ, Cavalcante LM, Silikas N. Shrinkage Stresses Generated during Resin–Composite Applications: A Review. *J Dent Biomech* 2010; 2010:1–14.
5. Tantbirojn D, Versluis A, Pintado MR, DeLong R, Douglas WH. Tooth deformation patterns in molars after composite restoration. *Dent Mater* 2004; 20:535–542.
6. Moazzami SM, Sarabi N, Hajizadeh H, Majidinia S, Li Y, Meharry MR, et al. Efficacy of four lining materials in sandwich technique to reduce microleakage in class II composite resin restorations. *Oper Dent* 2014;39:256–263.
7. Ferracane JL. Placing Dental Composites—A Stressful Experience. *Oper Dent* 2008;33:247–257.
8. Hilton TJ. Cavity sealers, liners, and bases: current philosophies and indications for use. *Oper Dent* 1996;21:134–146.
9. Suzuki M, Jordan RE. Glass Ionomer–Composite Sandwich Technique. *J Am Dent Assoc* 1990;120:55–57.
10. van Dijken JWV. A 6–year evaluation of a direct composite resin inlay/onlay system and glass ionomer cement–composite resin sandwich restorations. *Acta Odontol Scand* 1994;52:368–376.
11. Veloso SRM, Lemos CAA, de Moraes SLD, do Egito Vasconcelos BC, Pellizzer EP, de Melo Monteiro GQ. Clinical performance of bulk–fill and conventional resin composite restorations in posterior teeth: a systematic review and meta–analysis. *Clin Oral Investig* 2019;23:221–233.
12. Montes MAJR, de Goes MF, da Cunha MRB, Soares AB. A morphological and tensile bond strength evaluation of an unfilled adhesive with low–viscosity composites and a filled adhesive in one

and two coats. *J Dent* 2001;29:435–441.
13. Watson TF, Atmeh AR, Sajini S, Cook RJ, Festy F. Present and future of glass–ionomers and calcium–silicate cements as bioactive materials in dentistry: Biophotonics–based interfacial analyses in health and disease. *Dent Mater* 2014; 30:50–61.
14. Koubi G, Colon P, Franquin J–C, Hartmann A, Richard G, Faure M–O, et al. Clinical evaluation of the performance and safety of a new dentine substitute, Biodentine, in the restoration of posterior teeth — a prospective study. *Clin Oral Investig* 2013;17:243–249.
15. Moon PC. Class II posterior composites––ways to reduce bond stress and microleakage by using low modulus materials. *Va Dent J* 1995;72:12–14.
16. Oliveira LCA, Duarte S, Araujo CA, Abrahão A. Effect of low–elastic modulus liner and base as stress–absorbing layer in composite resin restorations. *Dent Mater* 2010;26:159–169.
17. Tolidis K, Nobecourt A, Randall RC. Effect of a resin–modified glass ionomer liner on volumetric polymerization shrinkage of various composites. *Dent Mater* 1998;14:417–423.
18. Ikemi T, Nemoto K. Effects of Lining Materials on the Composite Resins Shrinkage Stresses. *Dent Mater J* 1994;13:1–8.
19. Reis AF, Giannini M, Ambrosano GMB, Chan DC. The effects of filling techniques and a low–viscosity composite liner on bond strength to class II cavities. *J Dent* 2003;31:59–66.
20. Castañeda–Espinosa JC, Pereira RA, Cavalcanti AP, Mondelli RFL. Transmission of composite polymerization contraction force through a flowable composite and a resin–modified glass ionomer cement. *J Appl Oral Sci* 2007; 15:495–500.
21. Magne P. Efficient 3D finite element analysis of dental restorative procedures using micro–CT data. *Dent Mater* 2007;23:539–548.
22. Chuang SF, Chang CH, Chen TY. Contraction behaviors of dental composite restorations––finite element investigation with DIC validation. *J Mech Behav Biomed Mater* 2011;4:2138–2149.
23. Versluis A, Tantbirojn D, Pintado MR, DeLong R, Douglas WH. Residual shrinkage stress distributions in molars after composite restoration. *Dent Mater* 2004;20:554–564.

24. Boaro LCC, Brandt WC, Meira JBC, Rodrigues FP, Palin WM, Braga RR. Experimental and FE displacement and polymerization stress of bonded restorations as a function of the C-Factor, volume and substrate stiffness. *J Dent* 2014;42:140-148.
25. Liu Z, Qian Y, Liu D, Yang J, Fan Y. Stress analysis of first permanent mandibular molar with class 1 restorations of different cement bases by occlusive load: A finite element analysis. *Int J Numer Meth Bio* 2010; 26:1371-1379.
26. Farah J, Powers J, Dennison J, Craig R, Spencer J. Effects of cement bases on the stresses and deflections in composite restorations. *J Dent Res* 1976; 55:115-120.
27. Ausiello P, Ciaramella S, Martorelli M, Lanzotti A, Gloria A, Watts DC. CAD-FE modeling and analysis of class II restorations incorporating resin-composite, glass ionomer and glass ceramic materials. *Dent Mater* 2017; 33:1456-1465.
28. Kim WH, Lee JC, Lim D, Heo YK, Song ES, Lim YJ, et al. Optimized Dental Implant Fixture Design for the Desirable Stress Distribution in the Surrounding Bone Region: A Biomechanical Analysis. *Materials* 2019;12:2749.
29. Girish K, Mandava J, Chandra RR, Ravikumar K, Anwarullah A, Athaluri M. Effect of obturating materials on fracture resistance of simulated immature teeth. *J Conserv Dent* 2017;20:115-119
30. Ausiello PP, Ciaramella S, Lanzotti A, Ventre M, Borges AL, Tribst JP, et al. Mechanical behavior of Class I cavities restored by different material combinations under loading and polymerization shrinkage stress. A 3D-FEA study. *Am J Dent* 2019;32:55-60.
31. Ausiello P, Ciaramella S, Fabianelli A, Gloria A, Martorelli M, Lanzotti A, et al. Mechanical behavior of bulk direct composite versus block composite and lithium disilicate indirect Class II restorations by CAD-FEM modeling. *Dent Mater* 2017;33:690-701.
32. Dalpino PHP, Francischone CE, Ishikiriama A, Franco EB. Fracture resistance of teeth directly and indirectly restored with composite resin and indirectly restored with ceramic materials. *Am J Dent* 2002;15:389-394.
33. Kelly JR, Campbell SD, Bowen HK. Fracture-surface analysis of

dental ceramics. *J Prosthet Dent* 1989;62:536–541.
34. Thompson JY, Anusavice KJ, Naman A, Morris HF. Fracture surface characterization of clinically failed all–ceramic crowns. *J Dent Res* 1994; 73:1824–1832.
35. Saini H, Ackland DC, Gong L, Cheng LK, Rohrle O. Occlusal load modelling significantly impacts the predicted tooth stress response during biting a simulation study. *Comput Methods Biomech Biomed Engin* 2020;23:261–270
36. Davidson CL, Feilzer AJ. Polymerization shrinkage and polymerization shrinkage stress in polymer–based restoratives. *J Dent* 1997;25:435–440
37. Braga RR, Ballester RY, Ferracane JL. Factors involved in the development of polymerization shrinkage stress in resin–composites: a systematic review. *Dent Mater* 2005;21:962–970.

Tables and Figures

Table 1 – Total number of elements and nodes of all FEA models.

Group	Material	Number of nodes	Number of elements
Sound tooth	Enamel	370,671	66,276
	Dentine	434,377	83,179
Group A	Enamel	230,414	46,489
	Dentine	744,944	136,448
	Adhesive layer	176,357	49,074
	Composite Resin	613,401	116,798
Group B	Enamel	602,860	114,946
	Dentine	744,944	136,448
	Resin Cement	292,436	75,214
	Lithium Disilicate	602,860	114,946
Group (C, D, E)–tn	Enamel	233,840	47,087
	Dentine	629,214	115,408
	Adhesive layer	169,795	48,765
	Base	199,500	39,136
	Composite Resin	483,305	92,177
Group (C, D, E)–tk	Enamel	230,412	117,394
	Dentine	754,577	137,992
	Adhesive layer	196,816	54,229
	Base	305,127	57,360
	Composite Resin	502,298	95,867

Table 2 – Mechanical properties data used in the study.

Type	Material	Young's modulus (GPa)	Poisson's ratio	Linear thermal expansion coefficient	Refer–ences
Tooth structure	Dentin	18	0.23		[27]
	Enamel	80	0.3		[27]
Food Bolus	Food bolus	3.4	0.1		[30]
Resin materials	Direct composite resin	12	0.25	0.01	[27]
	Adhesive layer	4	0.3	0.01	[27]
Base materials	Glass Ionomer Cement	8	0.25		[27]
	Low viscosity resin	6	0.3	0.01	[27]
	Tricalcium silicate cement	22	0.3		[29]
Indirect ceramic Group	Lithium disilicate	70	0.25		[27]
	Luting resin cement	6	0.3	0.01	[27]

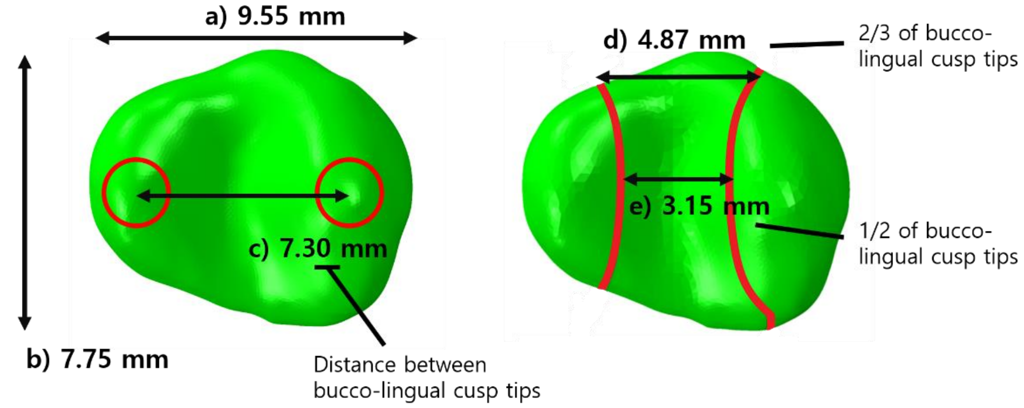

Fig. 1 – Illustration of inlay preparation design. (a) bucco–lingual dimension of tooth model, (b) mesio–distal dimension of tooth model, (c) distance between bucco–lingual cusp tips, (d) widths of proximal boxes, and (e) width of occlusal cavity.

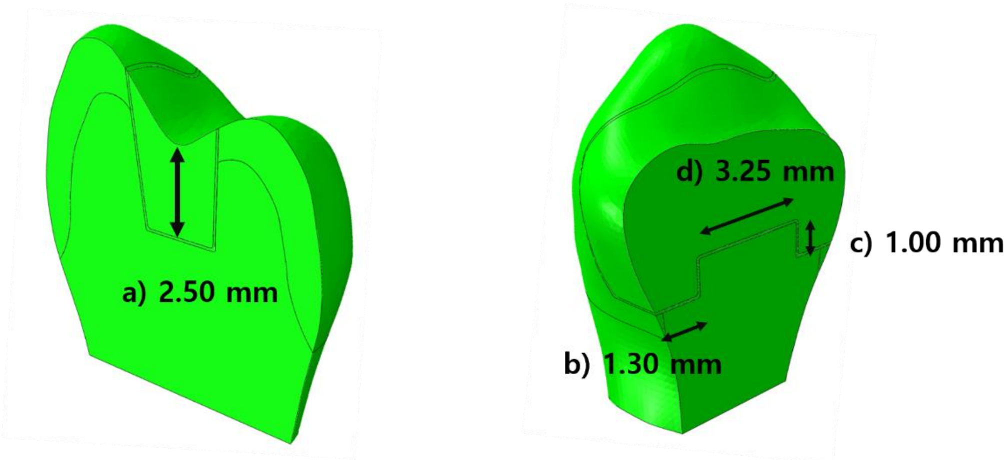

Fig. 2 – Illustration of inlay preparation design. (a) depth of cavity, (b) length of proximal boxes, (c) height of axial wall, and (d) length of pulpal floor.

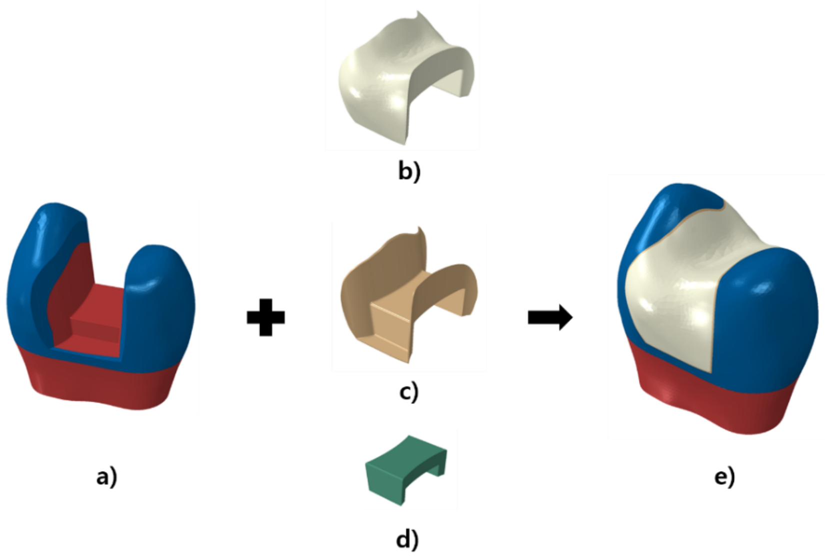

Fig. 3 – Illustration of study model design. (a) dentin and enamel, (b) composite resin, (c) adhesive layer, (d) intermediate base, and (e) restored tooth.

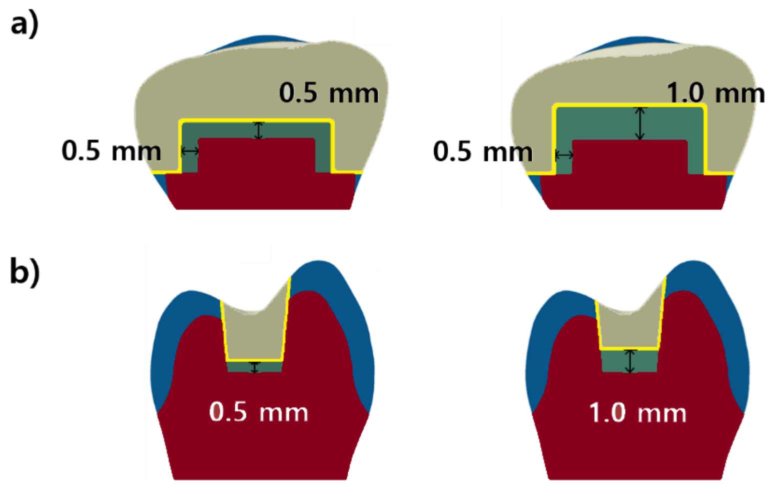

Fig. 4 – Model design of thin (left) and thick (right) base material. (a) mesio–distal cross–sectional view, and (b) bucco–lingual cross–sectional view.

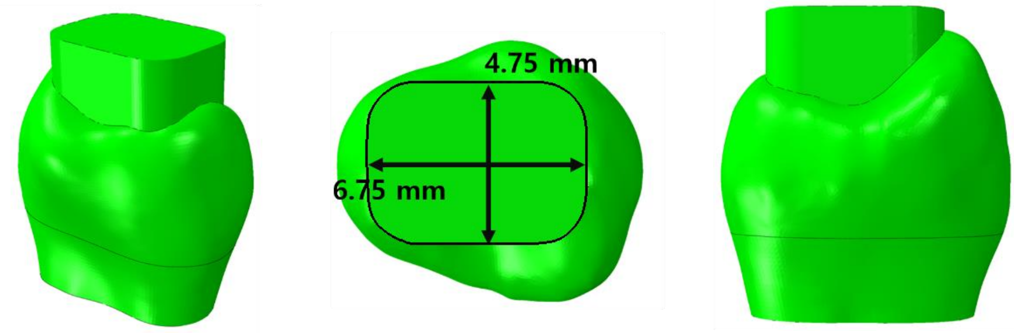

Fig. 5 – Illustration on contact area between food bolus and tooth: width and length of food bolus.

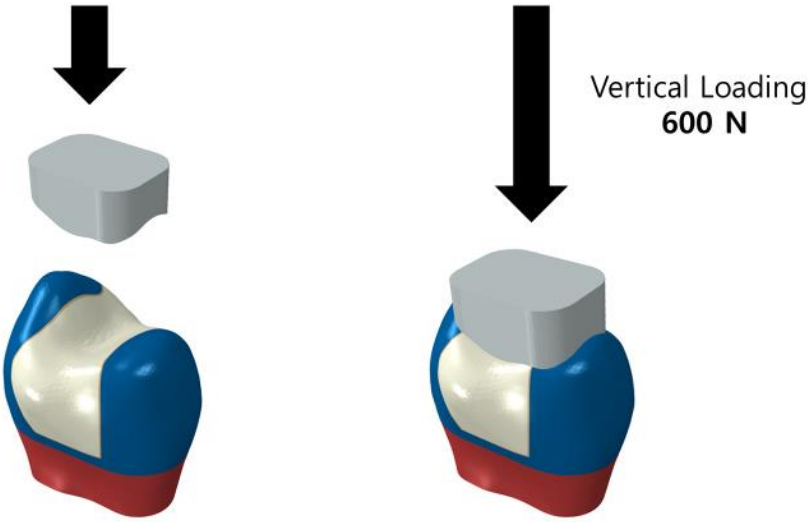

Fig. 6 – Illustration on tooth and food bolus: simulation of 600 N occlusal loading.

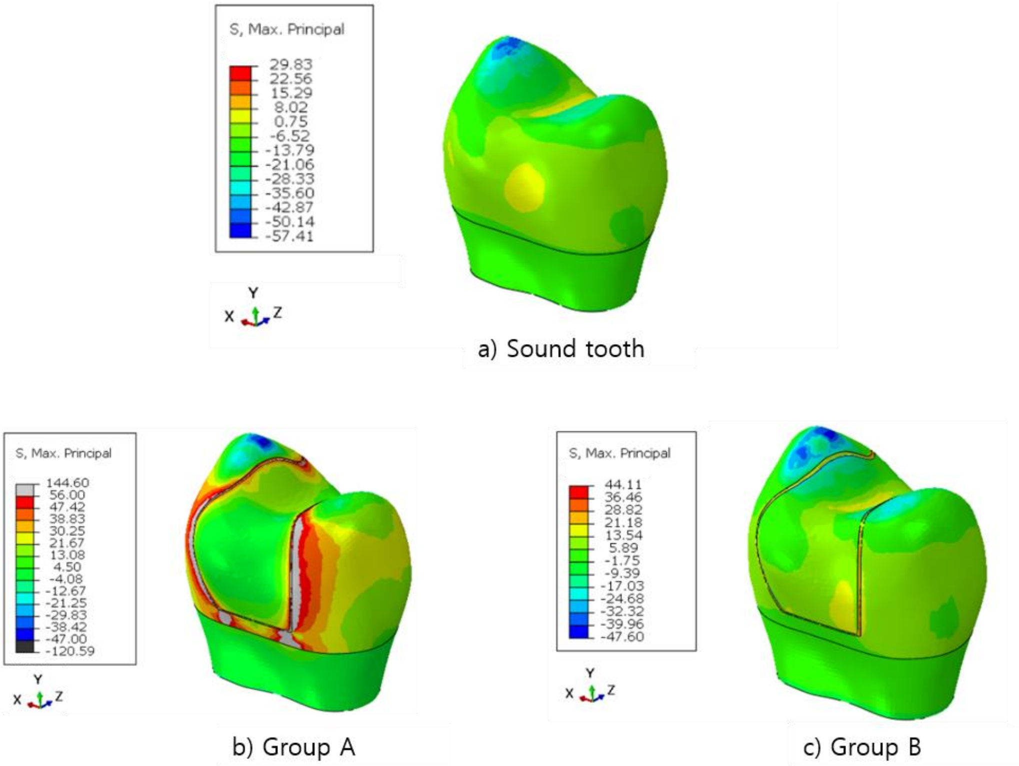

Fig. 7 – Stress distribution of sound tooth, Group A and B after shrinkage effect and 600 N vertical loading in outer view. (a) Sound tooth, (b) Group A, and (c) Group B.

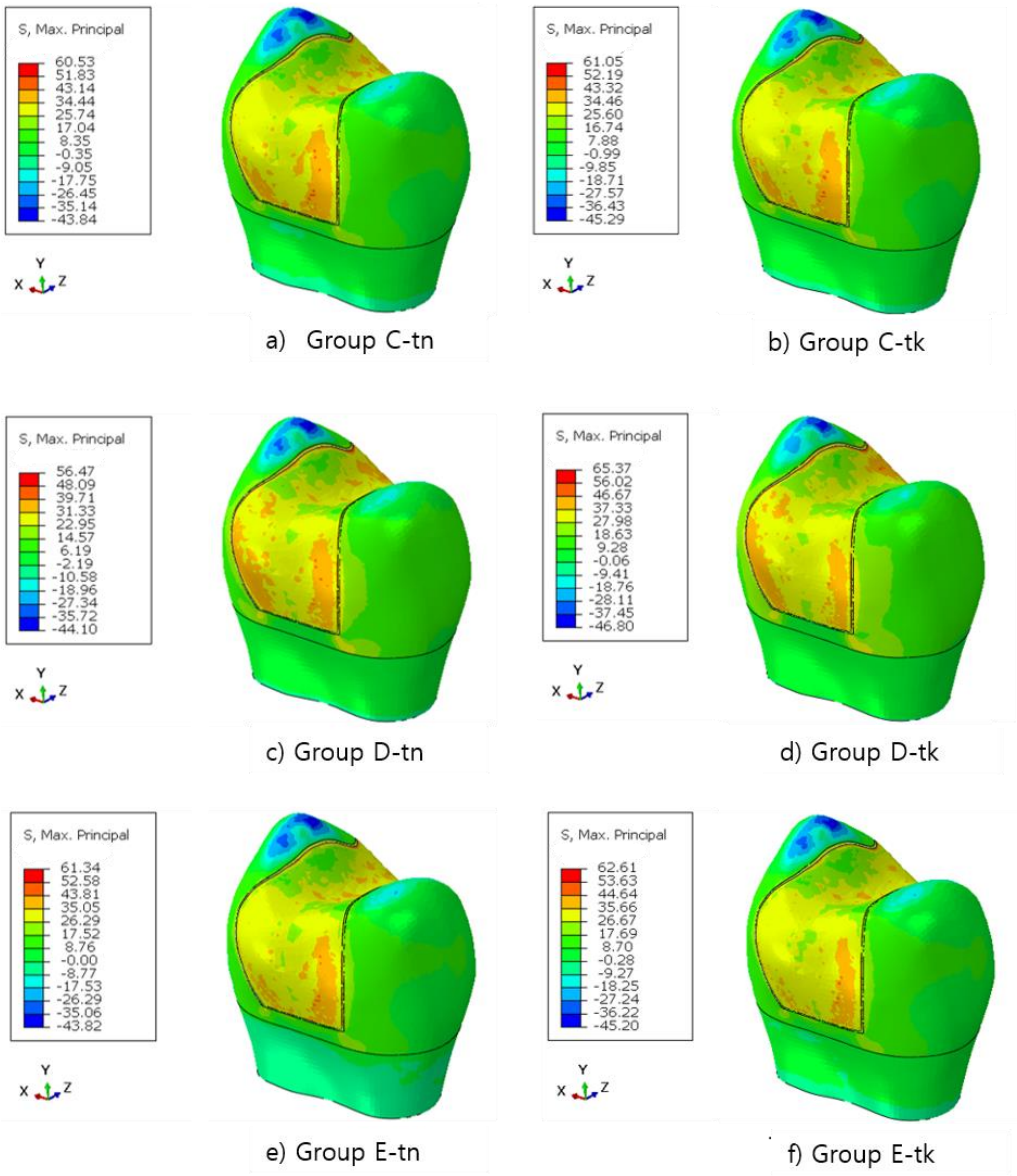

Fig. 8 – Stress distribution of Group C, D and E after shrinkage effect and 600 N vertical loading in outer view. Thin base groups are on left (a, c and e), and thick base groups are on right. (b, d and f)

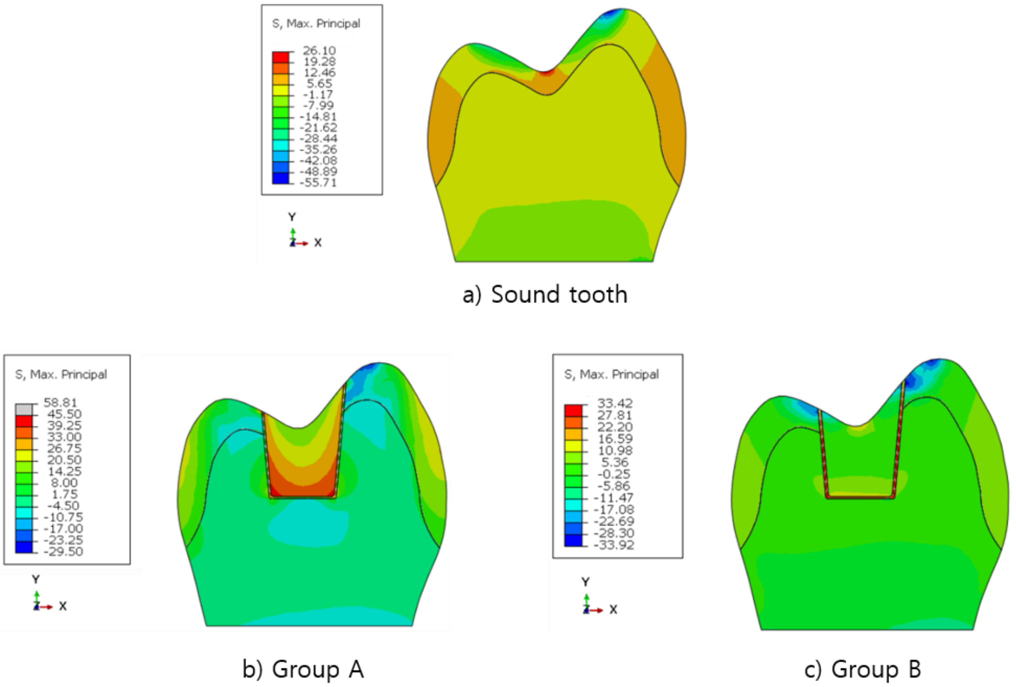

Fig. 9 – Stress distribution of sound tooth, Group A and B after shrinkage effect and 600 N vertical loading in bucco-lingual cross-sectional view. (a) Sound tooth, (b) Group A, and (c) Group B.

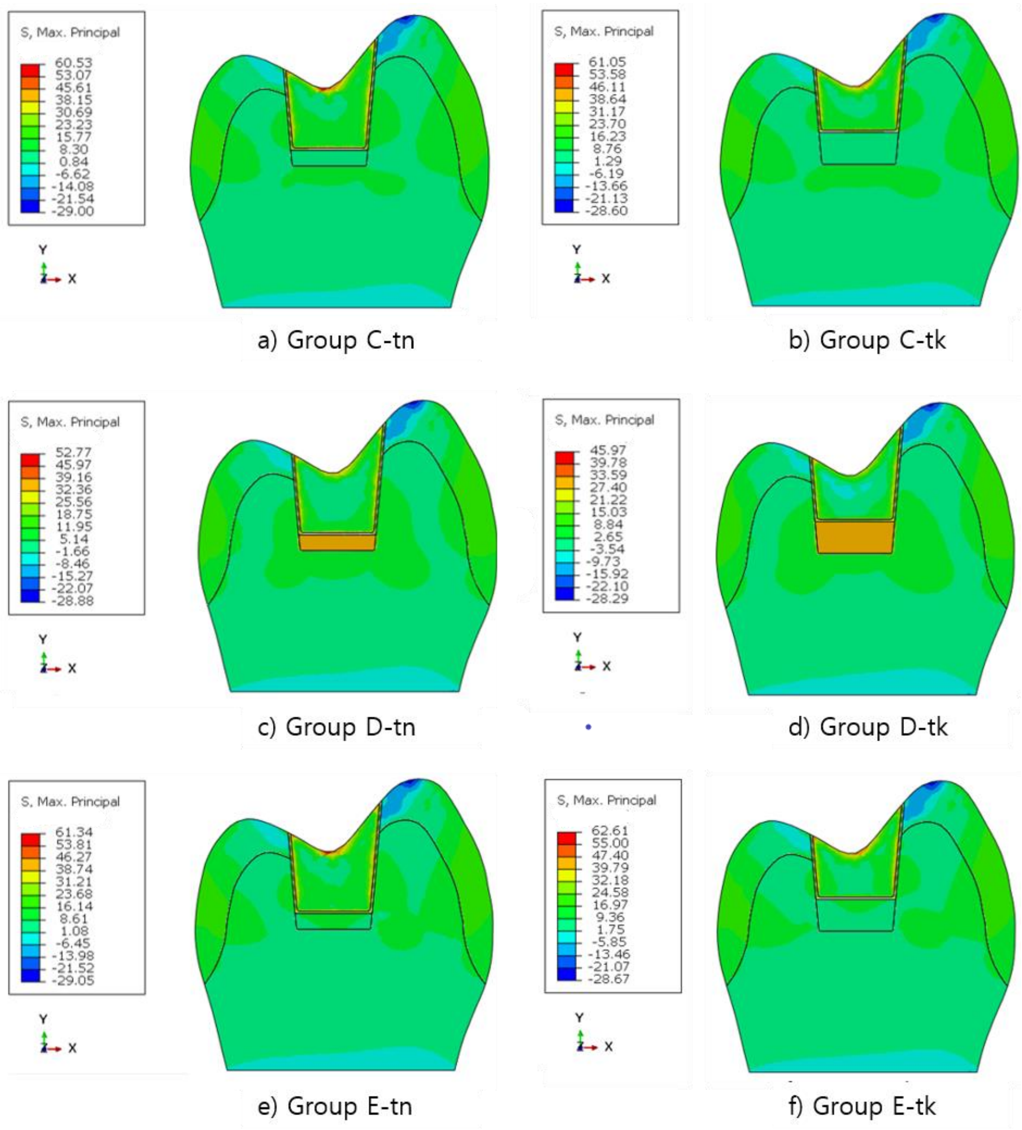

Fig. 10 – Stress distribution of Group C, D and E after shrinkage effect and 600 N vertical loading in bucco–lingual cross–sectional view. Thin base groups are on left (a, c and e), and thick base are on right. (b, d, f)

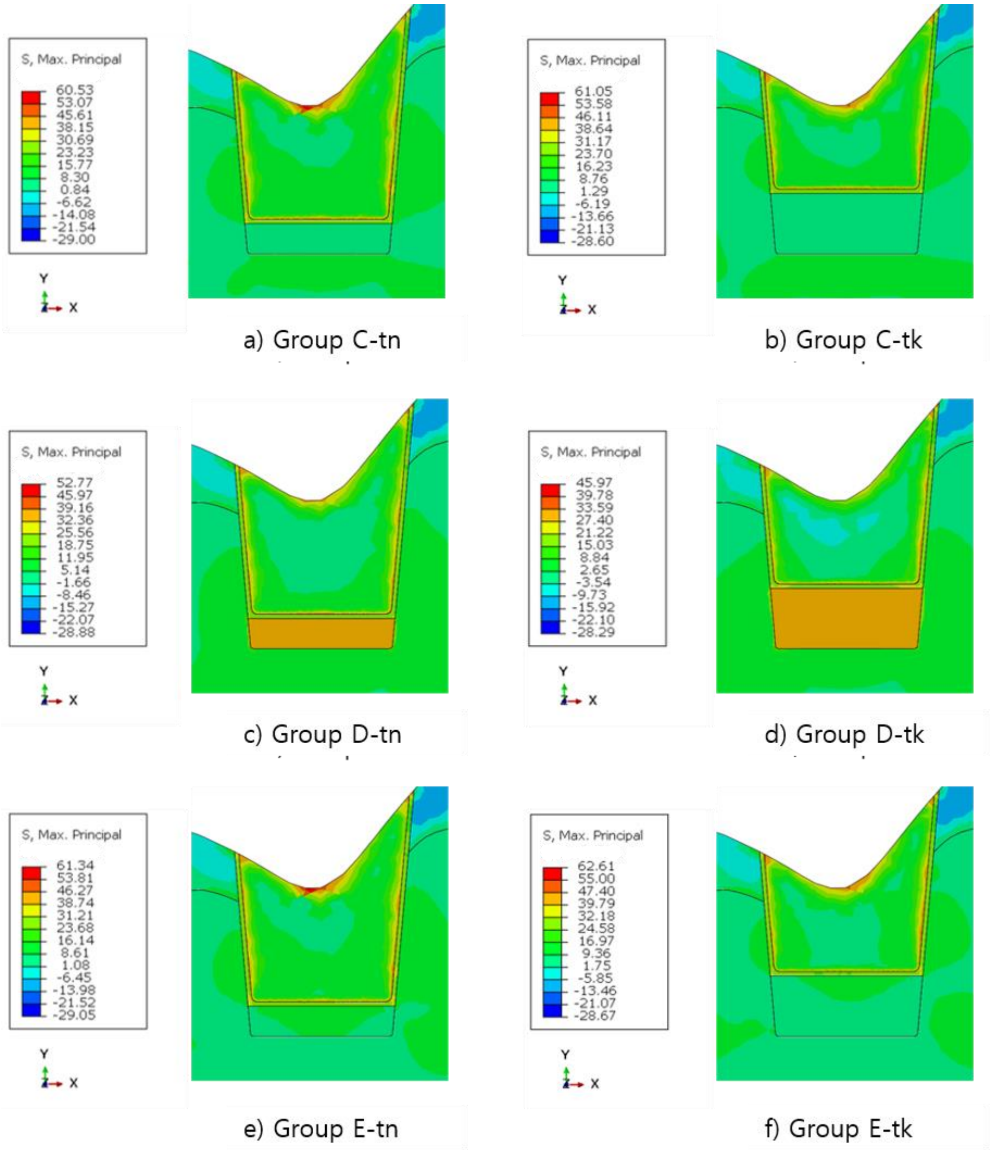

Fig. 11 – A detailed view on stress distribution of composite resin of Group C, D and E after shrinkage effect and 600 N vertical loading in bucco–lingual cross–section. Thin base groups are on left (a, c and e), and thick base groups are on right. (b, d, f)

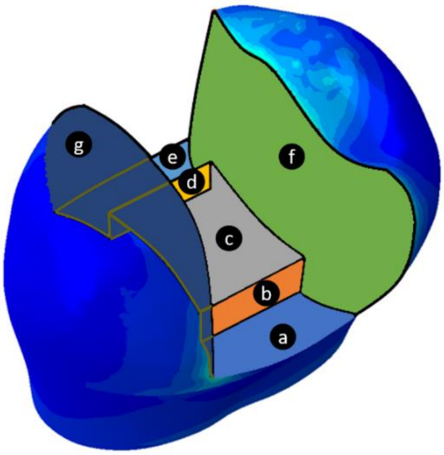

Fig. 12 – All inter–surfaces of tooth underneath restorations. (a) disto–gingival floor, (b) disto–axial wall, (c) pulpal floor, (d) mesio–axial wall, (e) mesio–gingival floor, (f) buccal wall, and (g) lingual wall.

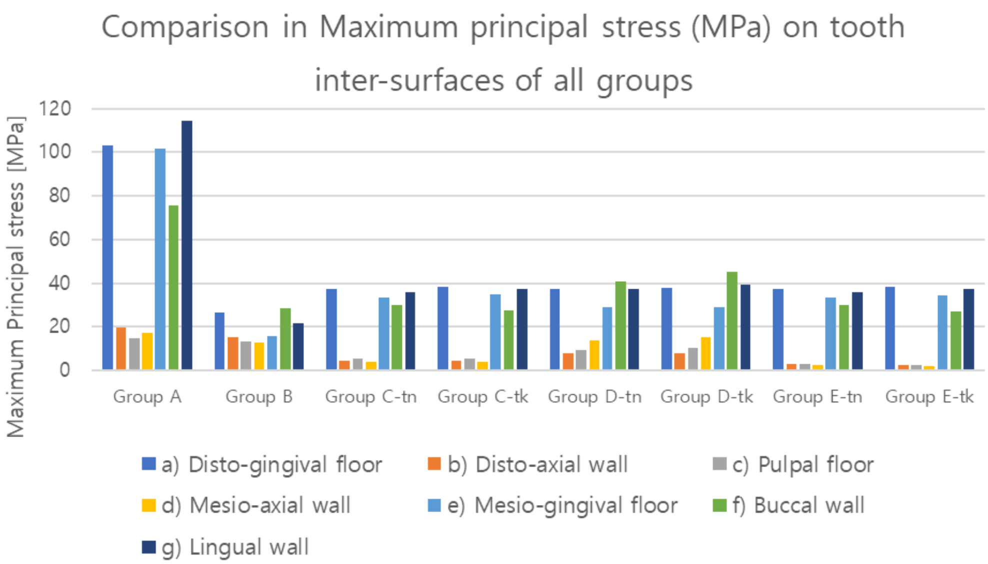

Fig. 13 – Comparison in Maximum principal stresses (MPa) on tooth inter–surfaces of all groups.

국문초록

Class II MOD 직접 복합 레진 수복 시 기저재의 종류와 두께에 따른 응력 분포의 비교: 삼차원 유한요소연구

치의과학과 치과보존학 전공
(지도교수 서 덕 규)
정 민 관

1. **목 적**

본 연구의 목적은 Class II MOD 직접 복합 레진 수복 시 Base 재료의 종류 및 두께에 따른 응력 분포를 3D 유한 요소 해석법을 통해 비교 분석하는 것이다.

2. **방 법**

CBCT-scan 데이터를 기반으로 한 9개의 삼차원 치아 모형을 유한요소 소프트웨어 (Abaqus CAE 2016, Dassault systems, Velizy-Villacoublay, France)를 이용해 제작하였으며 형성된 유한요소 모형의 실험군을 다음과 같이 분류하였다.

Control Group: 정상 치아 (Sound tooth)
Group A: Base를 적용하지 않은 직접 수복 Composite Resin
Group B: Resin luting cement를 적용한 간접 수복 Lithium disilicate
Group C-tn: Composite resin 과 Glass ionomer cement base 0.5 mm
Group C-tk: Composite resin 과 Glass ionomer cement base 1.0 mm
Group D-tn: Composite resin 과 Low-viscosity resin base 0.5 mm
Group D-tk: Composite resin 과 Low-viscosity resin base 1.0 mm
Group E-tn: Composite resin 과 Tricalcium silicate cement base 0.5

mm
Group E-tk: Composite resin 과 Tricalcium silicate cement base 1.0 mm

Group C, D, E 는 공통적으로 adhesive layer 와 base 그리고 composite resin 으로 구성된 다층 구조로 형성되었으며, 이 3 개의 그룹을 다시 두께에 따라 thin (Tn, 0.5 mm) 과 thick (Tk, 1.0 mm), 2 개의 세부 그룹으로 나누었다. 레진 재료들의 중합 수축 효과와 함께 600 N 의 수직하중을 교합면에 가하고 모든 실험 모형들의 최대 주 응력 (Maximum principal stress) 분포 데이터를 도표 및 그림으로 시각화하여 비교 분석하였다.

3. 결 과

대조군에서는 응력 분포가 법랑질에 국한되어 고르게 분산되었으며 모든 실험군 중 가장 낮은 응력 값을 보였다. Group A 에서는 치아와 수복물의 계면을 따라서 가장 높은 응력 분포를 보였으며 특히 변연에서 파절 위험이 증가하였다. Group B의 경우 대조군을 제외한 모든 군에서 가장 낮은 응력 값을 보였으나 Resin cement layer 에 집중된 응력이 관찰되었다. Group C, D, E의 경우 Group A와 비교했을 시 Group C, D, E 모두 중합 수축에 의한 응력을 감소시켰으나, Base의 종류에 따른 응력 분포에 유의미한 차이는 없었으며 0.5 mm 과 1.0 mm의 두께에 따른 응력 분포에 차이는 없었다.

4. 결 론

Class II MOD 직접 레진 수복 시, Base의 적용은 중합 수축으로 인한 응력을 감소시켰으나 Base 재료 종류의 차이 그리고 0.5 mm 과 1.0 mm의 두께 차이가 응력의 분포에 미치는 영향은 없었다.

주요어 : 삼차원 유한요소법, 응력분포, 2급 MOD 와동, 중합수축, 기저재
학 번 : 2017-29948