Comparison of cuspal deflection in bulk or in incremental composite filling methods

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Comparison of cuspal deflection in bulk or in incremental composite filling methods

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Dec. 2006

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바쁜 레지던트 생활 중에도 군소리 없이 지난 일년간 실험을 도와준 이장호 선생, 영어문장을 세심하게 고쳐준 이윤 선생, 어려울때 마다 위로가 되어준 친구들 에게도 감사를 전합니다.

공부하는 딸과 며느리를 대신해서 우리 천사 같은 하은이 예은이 은호를 돌봐주시느라 언제나 수고하시는 어머니와 시어머님 그리고 시아버님께 이 자리를 대신해 감사드립니다. 항상 바쁜 엄마를 세상에서 가장 사랑해 주는 우리 세 남매와 공부하느라 멀리 있으면서도 논문을 고쳐주고 도와주고 조언을 아끼지 않았던 인생의 동반자인 이재익 선생과 이 기쁨을 함께 하고 싶습니다.

저를 여기까지 있게 하시고 항상 은혜로 저의 삶을 함께 하시는 하나님께 이 모든 감사를 돌려 드립니다.

감사합니다.

2006년 12월

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Abstract

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The aim of this study was to compare the cuspal deflection of the maxillary premolars when a bulk filling and incremental filling technique was used with various composites each with a different elastic modulus. Four brands of composite materials; Heliomolar, Heliomolar HB, Filtec Supreme XT and Renew and three filling technique; bulk filling, two-layer incremental filling and three-layer incremental filling methods were used. One hundred twenty caries-free human premolar teeth were collected and divided into 4 groups according to the filling materials and then subdivided into 3 groups according to the filling methods. In Group 1, a bulk filling of 0.15 g of each resin was inserted and light-cured with LED light at the occlusal, mesial and distal surfaces for 60 seconds each. Group 2 was given two horizontal fillings of 0.08 g and 0.07 g with each filling being light-cured to the occlusal, mesial and distal surfaces for 30 seconds for each increment. In Group 3, there were three horizontal fillings of 0.05 g, each of which was light-cured to the occlusal, mesial and distal surfaces for 20 seconds each. The cuspal deflections were measured using a customized cuspal deflection measuring machine (CDMM) for 10 minutes from the initiation of light polymerization. The elastic modulus of each composite resin material was measured using a three-point bending test and the level of volumetric shrinkage was measured using an AcuVol (Bisco co. U.S.A.). The cuspal deflection measurements were analyzed statistically using a two-way ANOVA and one-way ANOVA test. The relationship between the amount of cuspal deflection of each group and the elastic modulus of the composite and volumetric shrinkage were analyzed using a Pearson correlation test. There was a statistically significant difference in the level of cuspal deflection between Groups 1 and 3 for the four resin materials. In addition, there was statistically significant difference in the elastic modulus for each resin material. The amount of volumetric shrinkage was similar among resin materials. Statistical analysis showed a positive correlation between the cuspal deflection (group 1, 2, 3) and the elastic modulus of the composite. However, there was no significant correlation between the cuspal deflection and the amount of volumetric shrinkage.

These results demonstrated that the cuspal deflection was lower in the incremental filled cavity than in the bulk filled cavity and the elastic modulus of the composite had an influence on cuspal deflection.

Key words : Cuspal deflection, Bulk filling, Incremental filling, Elastic modulus Composite, Volumetric shrinkage.

Comparison of cuspal deflection

in bulk or in incremental composite filling methods

Department of Dentistry, Graduate School, Yonsei University

Directed by Prof. Sung-Ho Park, *D.D.S. Ph.D*

Myung Eun Kim

I. Introduction

The use of composite resin for tooth restorations has become commonplace due to the increasing patient demand for more aesthetic restorations. Resin-based materials have the advantage of being able to bond to the tooth structure. However, the significant disadvantages of these materials are the high level of polymerization shrinkage and thermal contraction. Resin based dental composite materials exhibit a reduction in volume of between 1 and 5% during polymerization (Bandyopadhyay, 1982; Goldman, 1983). This shrinkage causes stress that may pull the composite from the tooth structure to which it is bonded. Polymerization shrinkage stresses have the potential to initiate the failure of the composite-tooth interface (adhesive failure), which can cause microleakage and secondary dental caries (Jensen and Chan, 1985). It may also initiate microcracks in the restorative material. Polymerization contraction stresses transferred to the tooth cause tooth deformation (Suliman *et al.*, 1994). In the posterior teeth, polymerization shrinkage also results in movement toward the centre of the restoration, and in extreme cases can cause a cusp to fracture. It has been reported that placing a composite into class II cavities leads to an inward deformation of the cusp with an amount of deformation being observed to vary from 15 to 50 μm (Suliman *et al.*, 1993). There are many factors that influence the level of cuspal deflection such as the size and shape of the cavity (Meredith and Setchell, 1997), Young's modulus of the composite resin (Ausiello *et al.*, 2001), the system of polymerization (Abbas *et al.*, 1999), the bond strength of the dentin bonding agents and the placement techniques (Segura and Donly, 1993). Instead of bulk filling, many clinicians have suggested incremental filling technique to minimize the amount of cuspal movement compared. Some studies have reported that the amount of cuspal deflection was reduced when the cavities were restored with a composite placed in multiple but small increments

(Jensen and Chan, 1985; Segura and Donly, 1993). However, it is unclear if incremental filling can reduce cusp deflection compared with bulk filling. Some articles have claimed that there is no evidence of incremental filling having an advantage over bulk filling (Crim and Chapman, 1986; Rees *et al.*, 2004; Hyun and Park, 2006). It has been reported that there is no significant difference in the reduction of cuspal deflection between bulk filling and incremental filling techniques.

Polymerization shrinkage stress is affected by the elastic modulus of the composite resin material. Ausiello *et al.* (2006) reported that the cusp displacement was higher for a composite with a high elastic modulus due to prestressing from polymerization shrinkage, and the amount of cuspal movement was found to be lower than with a more flexible composite (Ausiello *et al.*, 2001). Rees *et al.* (2004), and Hyun and Park (2006) reported no significant difference in the cusp flexure between the bulk and incremental placement. They used Heliomolar, which has a low elastic modulus that may lead to less cuspal deflection. The composite with a low elastic modulus may relieve shrinkage stress on account of its flexibility.

The aim of this study was to compare the cuspal deflection of the maxillary premolars when a bulk filling and incremental filling technique was used with various composites each with a different elastic modulus.

II. Materials and methods

1. Cuspal deflection measurement

One hundred twenty intact human maxillary premolars were collected immediately after extraction and stored in a saline solution. Four different composites of A2 shade were used (Table 1). Each material group was subdivided into three groups according to the filling methods: Group 1, bulk placement; Group 2, horizontal placement of two layers, and Group 3, horizontal placement of three layers (Table 2).

Table 1. Restorative materials used in this study.

Materials	Manufacturer
Heliomolar	Ivoclar Vivadent, Schaan, Liechtenstein
Heliomolar HB	Ivoclar Vivadent, Schaan, Liechtenstein
Filtec supreme XT	3M Dental Products, St. Paul, MN, U.S.A
Renew	Bisco Inc., Schaumburg, IL, U.S.A.

Table 2. Three groups according to the cavity filling methods and curing time.

	Methods	Composite (g)	Curing time (s)
Group 1	Bulk filling	0.15	60+ 60+ 60
Group 2	2 layer Increments	0.8 + 0.7	(30+ 30+ 30)+ (30+ 30+ 30)
Group 3	3 layer Increments	0.5 + 0.5 + 0.5	(20 + 20 + 20)+ (20+ 20+ 20)+ (20 + 20 + 20)

a. Preparation of modified MOD cavity and composite placement.

The tooth specimens were stored in a saline solution from the time of extraction until cavity preparation. Before preparing the teeth, an outline of the cavity was drawn with a lead pencil, and the parallel-sided MOD cavity without buccal or lingual extension was then cut at a dimension of 3.5 mm buccolingually and 3 mm in depth from the occlusolingual carvosurface margin, using diamond burs with water spray-cooling (Fig. 1). This dimension was verified using a prefabricated hexahedral resin block, which was of the same size as the cavity dimension. The block was placed into the cavity and the preparation was adjusted until it fitted the prepared cavity.

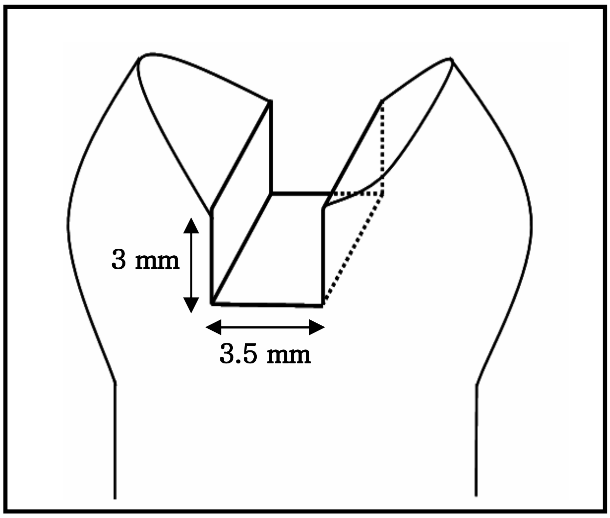


Fig. 1. Schematic representation of the parallel-sided, tunnel-shaped MOD cavity.

The cavities were flushed with copious amounts of water and completely dried. AdheSE (Ivoclar Vivadent, Schaan, Liechtenstein) was then applied according to the manufacturer's instructions. A total of 0.15 g of each resin material was used to fill the cavities in group 1, 2, and 3. In group 1 a bulk filling of 0.15 g was used. Group 2 had two separate fillings of 0.08 g and 0.07 g. In group 3, the cavities were filled with three separate fillings of 0.05 g each. The amount of the resin materials was weighed on an electronic balance and placed into the cavities.

b. Measurement of cuspal deflection.

The specimen was positioned in the cuspal deflection measuring machine (CDMM, R&B Inc., Daejon, Korea, Fig. 2). In order to minimize any tooth mobility, a specimen stabilizer made from a putty impression material was used to sustain the specimen (Fig. 3). The CDMM was designed to detect any deflection of the cusps during polymerization from the two measuring crossheads contacting the buccal and lingual surfaces. The right side measuring crosshead was attached to the linear guide and the left side measuring crosshead could alter its position as the cusps moved. The sensor linked to the left measuring crosshead was not attached to the other parts of the CDMM and it was not influenced by frictional force. The inward cuspal movement changed the position of left crosshead and it was detected by the sensor. The data were stored in computer simultaneously every 0.5 seconds for 10 minutes.

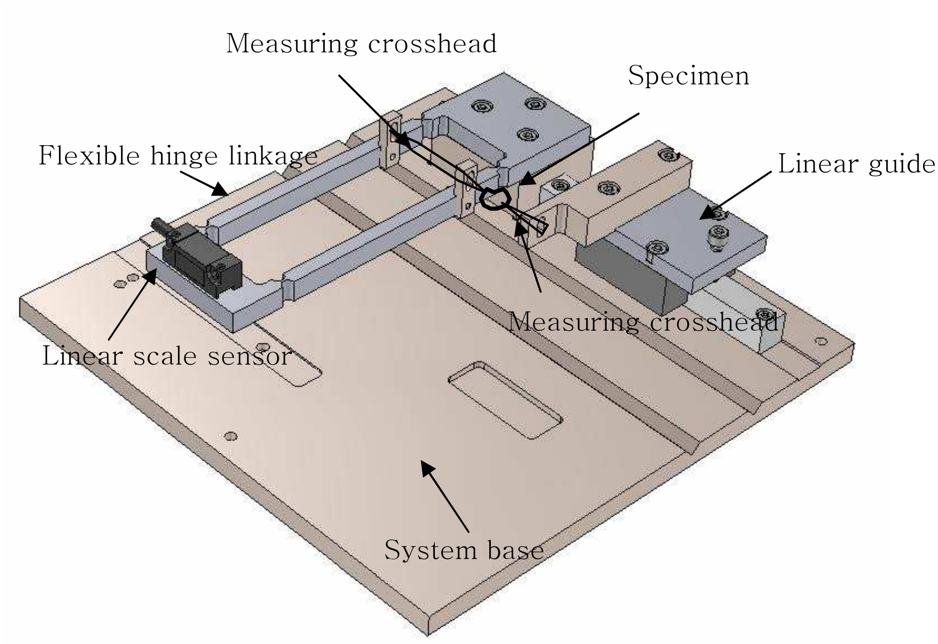


Fig. 2. Schematic drawing of the cuspal deflection measuring machine(CDMM).

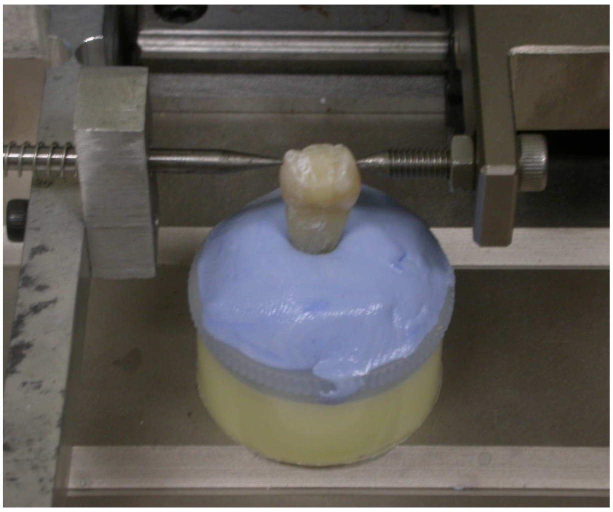


Fig. 3. Specimen placed in the CDMM.

Before light-curing, the initial distance sensed by the two crossheads was set at a baseline value of 0. As light-curing with a LED curing Light (Bluephase, Ivoclar Vivadent, Liechtenstein) began, the degree of inward cuspal movement was measured and recorded by the CDMM.

All the specimens in group 1 were light-cured at the occlusal, mesial and distal surfaces for 60 seconds each, making total curing time of 180 seconds. The tip of the curing light was kept within 2 mm of the tooth specimen. After light-curing was complete, the CDMM continued to record its measurement until 10 minutes had elapsed from the beginning of polymerization.

In group 2, each layer was light-cured at the occlusal, mesial and distal surfaces for 30 seconds, resulting in a total curing time of 180 seconds. In group 3, each increment was light-cured at the occlusal, mesial and distal surfaces for 20 seconds. Therefore the total curing time was 180 seconds in all three groups. The cuspal deflection measurement by the CDMM continued while the second and third fillings were placed on the top of the previous filling.

2. Elastic modulus measurement.

a. Preparation of test specimen.

Test specimen (25±2) mm x(2±0.1) mm x(2±0.1) mm were prepared using stainless steel mold according to ISO 4049.

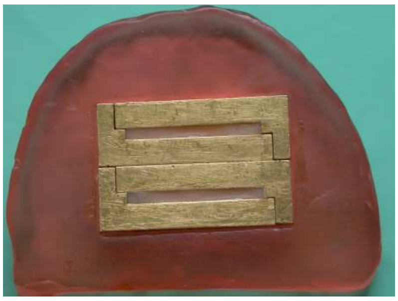


Fig. 4. Stainless steel mold for test specimen.

b. Three-point bending test

The flexural strength test apparatus was calibrated to provide a constant crosshead speed of (0.75±0.25) mm/min. The apparatus consisted essentially of two rods (2 mm in diameter) mounted parallel to each other with a 20 mm distance between the centers, with a third rod (2 mm in diameter) centered between and parallel to the other two, so that the three rods in combination could be used to give a three-point reference to the specimen (Fig. 5). The displacement of the resin specimen at a 10N loading was measured.

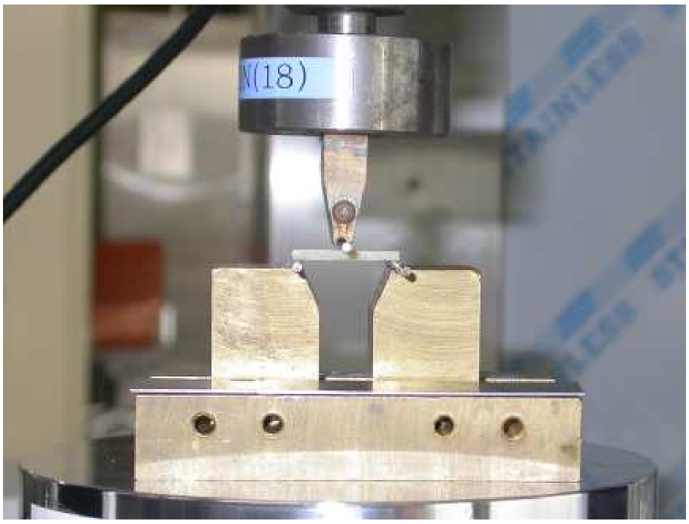


Fig. 5. Instron for three point bending test.

c. Treatment of result.

$$E = \frac{F1l^3}{4bh^3d}$$

E is elastic modulus.

$F1$ is the load, in Newton, at a convenient point (10N) in the straight-line portion of the tract.

d is the deflection, in millimeters, at load F1.

l is the distance, in millimeters, between the supports (20mm).

b is the width, in millimeters, of the specimen measured immediately prior to testing.

h is the height, in millimeters, of the specimen measured immediately prior to testing.

3. Measurement of Volumetric Shrinkage Percentage.

The percentage volumetric shrinkage was measured by AcuVol (Bisco co. Schaumburg, U.S.A.) (Fig. 6). The AcuVol calculates the absolute value of the percentage change in volume, which was displayed through percentage change analysis.

Fig. 6. Picture of AcuVol.

a. Measurement steps.

A 0.1g sample of a composite resin was placed on the pedestal, and the sample chamber was closed. The sample was allowed to settle on the pedestal for several minutes to allow the sample and chamber temperature to reach equilibrium. During this time, the sample volume was reconstructed and monitored continuously. When the sample volume reached a constant, the volumetric change was read. The sample chamber was opened and the sample was cured without removing the sample from the chamber using a curing light. The sample chamber was closed and the sample volume and percentage volume change were monitored.

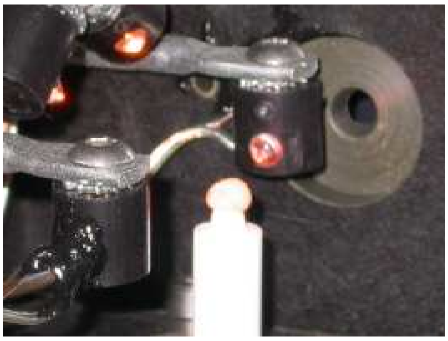


Fig. 7. Volumetric shrinkage measurement process.

4. Statistical analysis

The measurements of the cuspal displacement were analyzed using statistically two-way ANOVA with a Dunnet test. The cuspal deflection was also analyzed using one-way ANOVA with tukey to determine the difference between the groups within each composite material. The difference in the elastic modulus and volumetric shrinkage between the different materials were analyzed by one-way ANOVA and Tukey test.

Both the correlation between the amount of cuspal deflection and the elastic modulus of composite, and the correlation between the amount of cuspal deflection and the amount of volumetric shrinkage were analyzed using a Pearson correlation test.

III. Results

Table 3 shows the mean cuspal deflection in the four composite resin materials in the three groups. There were statistically significant differences in the amount of cuspal deflection between groups 1 and 3 for all resin materials ($p<0.05$) (Fig. 8).

Heliomolar HB showed significantly higher cuspal deflection than that of the other composite resins (Two-way ANOVA with Dunnet test, $p<0.05$) (Fig. 9).

The cuspal deflection in each group showed a characteristic pattern over the 10 minute period (Fig. 10, 11, 12, 13).

The elastic modulus in the Heliomolar, Heliomolar HB, Filtec supreme XT, Renew was 2.81 GPa, 7.76 GPa, 3.64 GPa and 4.32 GPa, respectively (Table 4). There was statistically significant difference in the elastic modulus for each resin material (Fig. 14).

The amount of volumetric shrinkage ranged from 2.84 to 3.37% (Table 5), there were no significant different between resin materials (Fig. 15).

Table 3. Mean value of cuspal deflection(㎛) (n=10).

	Group 1	Group 2	Group 3
Heliomolar	14.56±1,52	12.42±1.82	10.41±1.97
Heliomolar HB	19.33±3.48	16.17±1.37	14.33±1.92
Filtec supreme XT	15.22±1.49	12.45±1.07	11.58±2.27
Renew	14.43±0.56	12.02±2.37	10.33±1.65

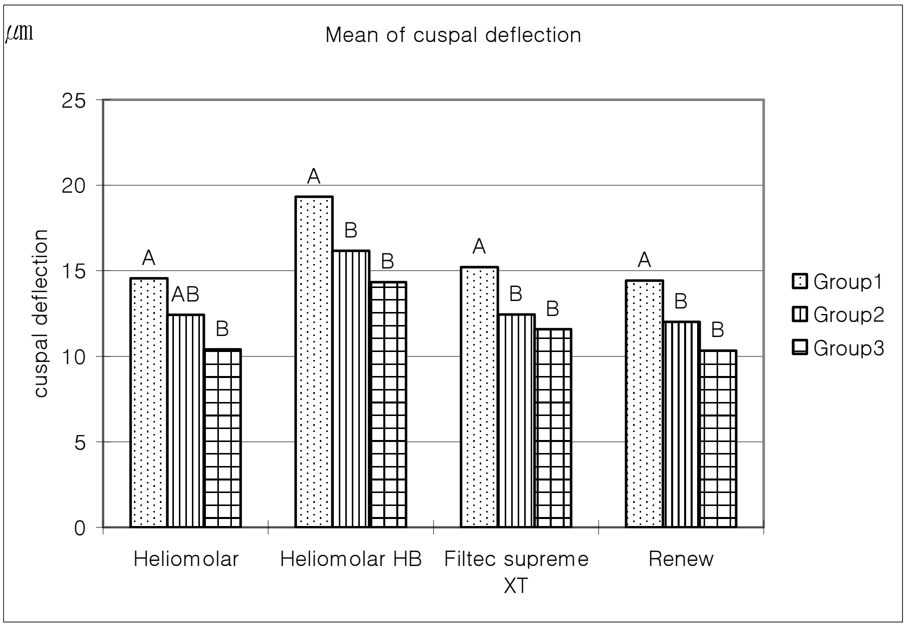


Fig. 8. Mean cuspal deflection of four resins.

*(A, B : same letters indicate no significant difference at P=0.05)

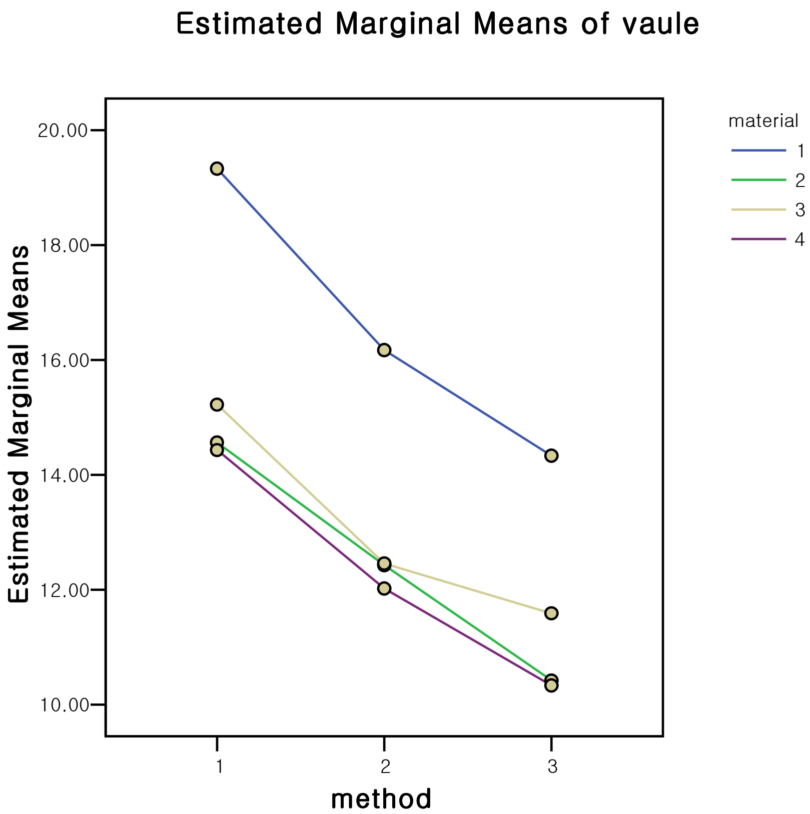


Fig. 9. Result of two-way ANOVA test.

*material 1: Heliomolar HB *material 2: Heliomoalr

*material 3: Filtec supreme XT *material 4: Renew

*method 1: Group 1 *method 2: Group 2

*method 3: Group 3

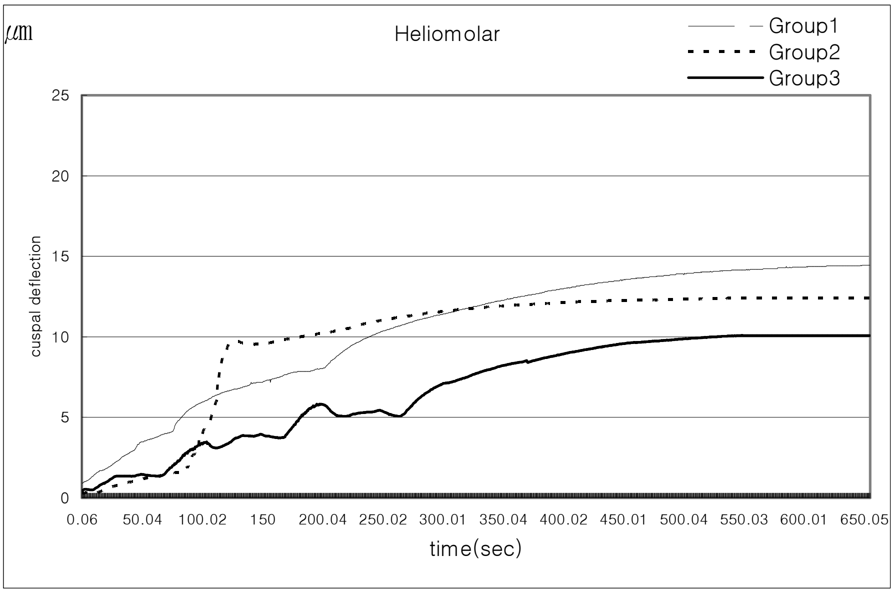


Fig. 10. Mean cuspal deflection of Heliomolar.

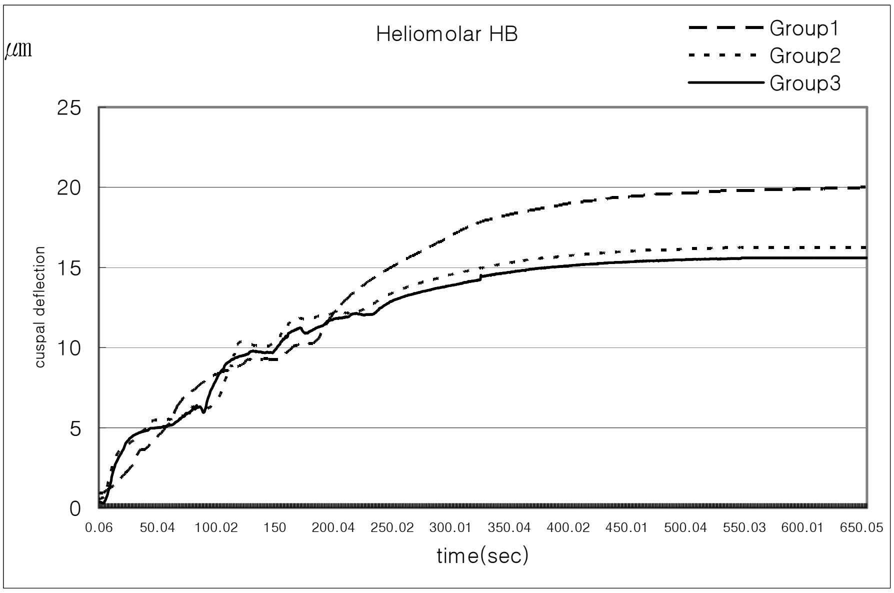


Fig. 11. Mean cuspal deflection of Heliomolar HB.

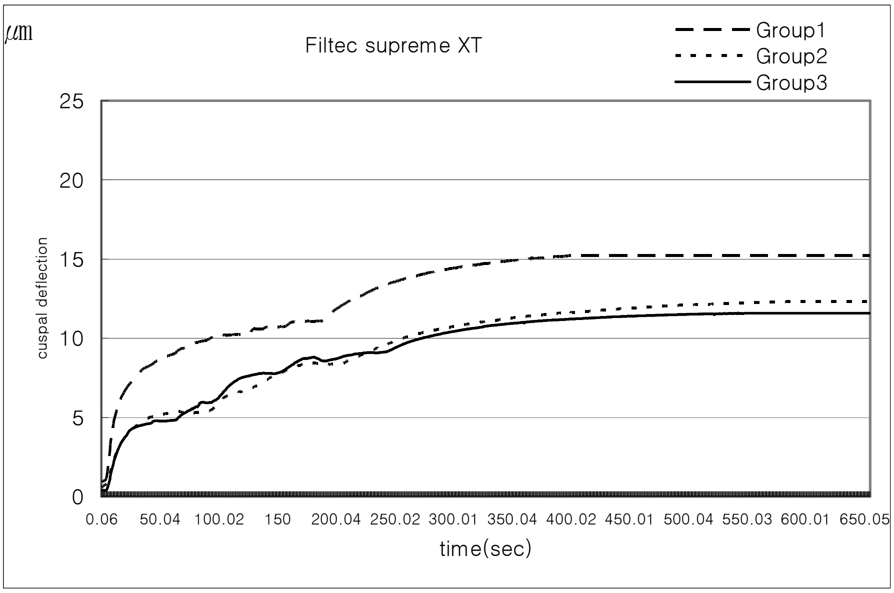


Fig. 12. Mean Cuspal deflection of Filtec supreme XT.

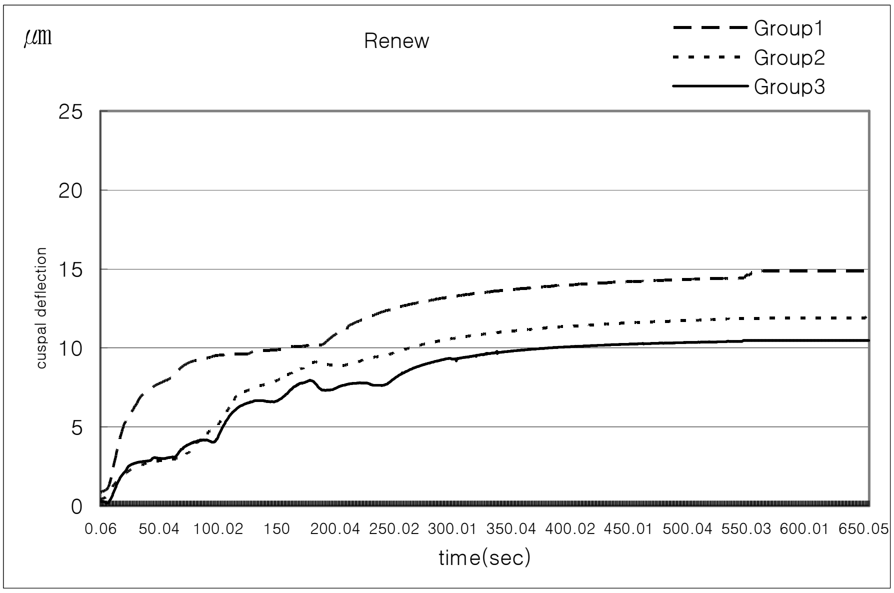


Fig. 13. Mean Cuspal deflection of Renew.

Table 4. Result of elastic modulus.

	F1(N)	D(mm)	E(GPa)
Heliomolar	10	0.44±0.03	2.81±0.23
Heliomolar HB	10	0.16±0.01	7.76±1.00
Filtec supreme XT	10	0.34±0.03	3.64±0.41
Renew	10	0.29±0.02	4.32±0.37

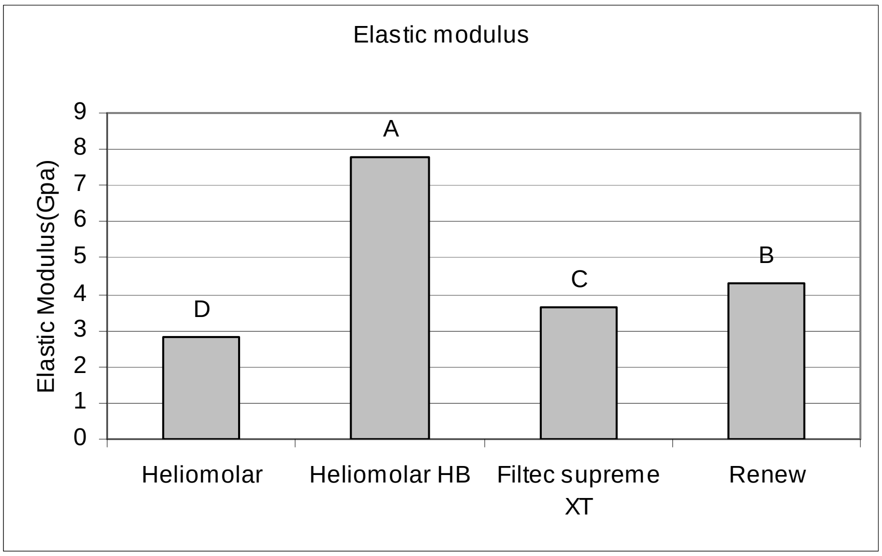


Fig. 14. Mean elastic modulus of four resin materials.

*(A, B, C, D : same letters mean no significant difference at P=0.05)

Table 5. Result of Volumetric Shrinkage (%).

Composite	Volumetric shrinkage
Heliomolar	3.22±0.61
Heliomolar HB	3.37±0.42
Filtec supreme XT	2.84±0.12
Renew	3.13 ±0.46

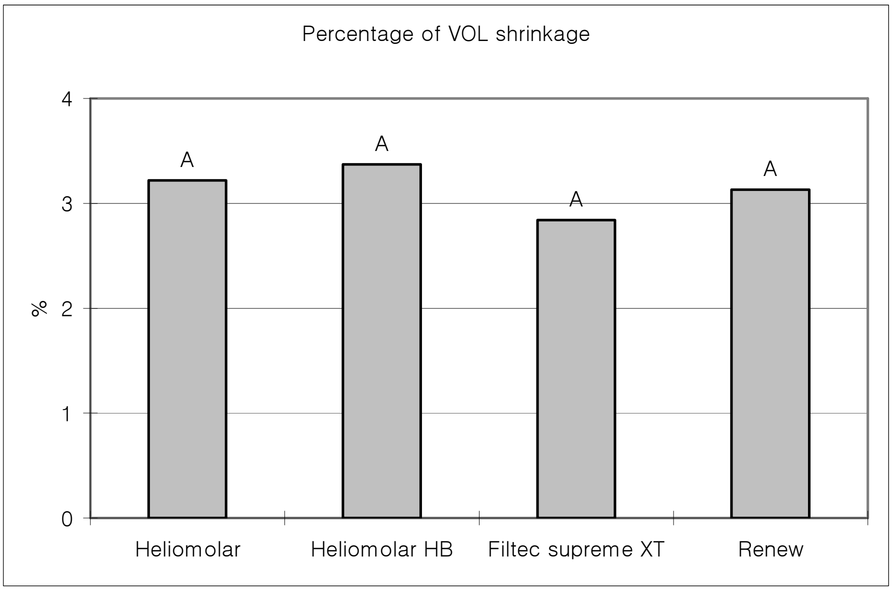
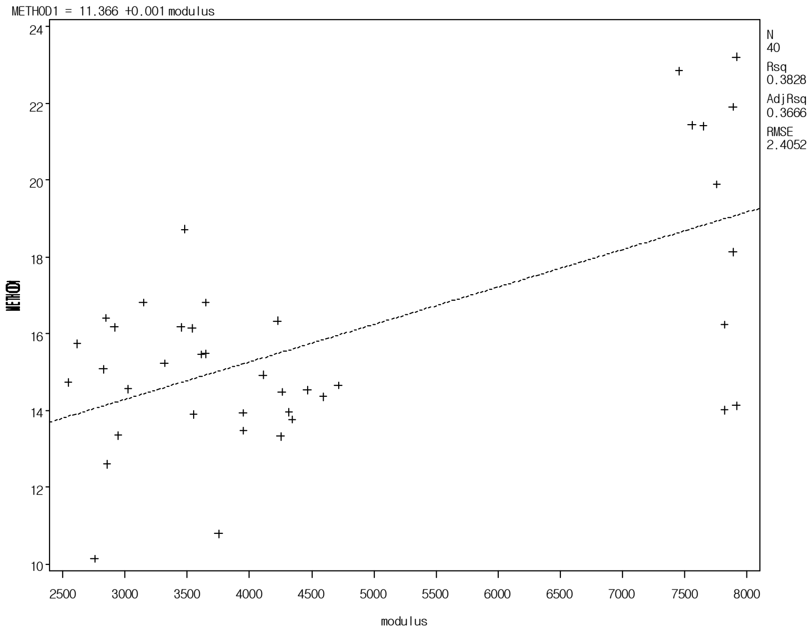


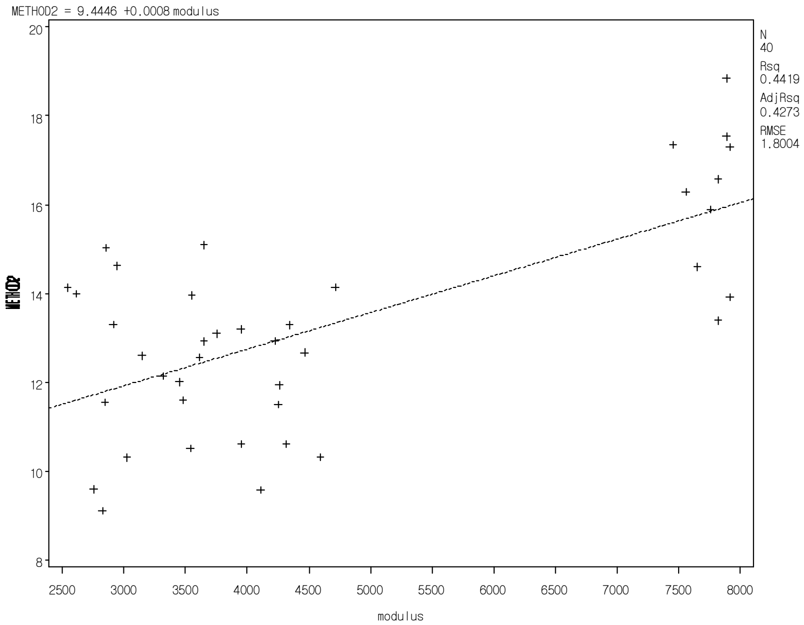
Fig. 15. Mean percentage of volumetric shrinkage.

*(A : same letters mean no significant difference at P=0.05)

a


METHOD1 = 11.366 +0.001 modulus
N
40
Rsq
0.3828
AdjRsq
0.3666
RMSE
2.4052
METHOD1
modulus

b


METHOD2 = 9.4446 +0.0008 modulus
N
40
Rsq
0.4419
AdjRsq
0.4273
RMSE
1.8004
METHOD2
modulus

c

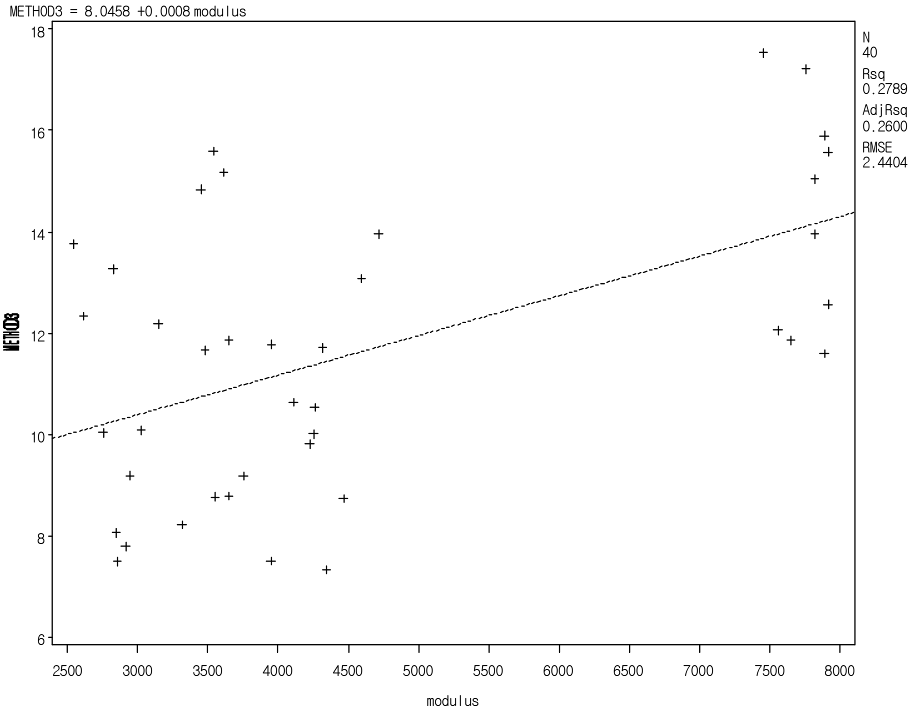


Fig. 16. a. Presentation of correlation between cuspal deflection (Group 1) and elastic modulus.

b. Presentation of correlation between cuspal deflection (Group 2) and elastic modulus.

c. Presentation of correlation between cuspal deflection (Group 3) and elastic modulus.

Statistical analysis revealed a positive correlation between the cuspal deflection and the elastic modulus of the composite (Pearson correlation constant = a:0.619, b:0.665, c:0.528, $p<0.01$, Fig. 16a, b and c). However, there was no correlation between the cuspal deflection and the amount of volumetric shrinkage.

IV. Discussion

The main finding of this study was that placing and curing a composite in increments reduces the amount of cuspal deflection.

The cuspal deflection of the bulk filling in this study was similar to the 15.30 ㎛ reported by Park (Park *et al.*, 2003). The cuspal deflection of resin placed using the other two techniques were also similar to the values, 6-15 ㎛, reported by McCullock and Smith (1986) and Rees *et al.* (2004). The cusps immediately and drastically deflected inwards toward the cavity as light-curing was begun but this tendency was offset by the thermal expansion of the tooth structure and the composite resin. This thermal expansion was supposedly due to the increase in temperature of the composite resin and the tooth specimen from the heat from the curing light and the exothermic reaction from the polymerization of the composite resin (Shortall and Harrington, 1998).

In this study, there was significant difference in cuspal deflection according to the filling technique ($p<0.05$). The cuspal deflection of the incrementally filled group was lower than that of the bulk filled group. The incremental filling technique lowers the C-factor (Lee and Lee, 2004), which has the advantage of reducing the level of stress associated with polymerization shrinkage. In addition, the incremental method is also more favorable than the bulk method due to the successful adaptation of the composite to the cavity wall, decreased microleakage as well as an increased degree of conversion (Rees *et al.*, 2004). The buildup of stress at the resin-tooth interface also depends on the elastic modulus of the composite (Feilzer *et al.*, 1990). Heavily filled hybrids have a higher elastic modulus than hybrids or microfills with less filler (Lambrechts *et al.*, 1998). Therefore, this study compared various resin materials with different elastic moduli. The elastic modulus of each material was measured using the three point bending test. Ausiello *et al.* (2001) reported that a high modulus restoration is associated with higher stress values. On the other hand, a less rigid restoration can reflex the applied stress through greater elastic deformation. A less rigid composite shows a greater elastic deformation that is transferred to lower levels of cusp deformation.

The elastic modulus represents the stiffness of a material within the elastic range. The elastic modulus can be determined from a stress-strain curve by calculating the stress to strain ratio or the slope of the linear region of the curve. The interatomic or intermolecular forces of the material were responsible for the elasticity. An increase in the basic attraction forces will increase the elastic modulus and produce a more rigid or stiffer material.

Some studies have reported no significant differences in cuspal deflection between fillings placed using incremental placement techniques and bulk placement techniques (Hyun and Park, 2006; Rees *et al.*, 2004). These studies used the dental composite, Heliomolar, which has high resin content, but a low conversion rate, and therefore less shrinkage (Suliman *et al.*, 1993). Heliomolar contain prepolymerized particles that do not contribute to polymerization shrinkage. According to this experiment, Heliomolar showed the lowest elastic modulus. Heliomolar can relieve the polymerization stress due to the low elastic modulus. Therefore, there would be a decrease in the amount of stress transferred to the tooth. Hence, the amount of cuspal deflection would be reduced. Interestingly, in this experiment, as in Hyun and Park's study (2006), there was no statistically significant difference in cuspal deflection between the two layer incremental technique and the bulk placement technique. It is possible that the amount of cuspal deflection caused by Heliomolar was so small that the difference in cuspal deflection between the two techniques was small. However, there was a significant difference in cuspal deflection between the bulk placement and the three layer incremental placement technique. In this study, Heliomolar HB which has the highest elastic modulus showed the largest cuspal deflection. Heliomolar HB falls into the category of what is known as a packable or condensable resin composite. This material has the characteristics of being less sticky as a result of the slight modification of the proportional composition of the monomer mixture. The compound silicate, which contains surface linked, long chain organic groups, increases the firmness of Heliomolar HB but does not compromise the modeling properties of the material.

The Pearson correlation test revealed a strong correlation between the elastic modulus of the composite and the cuspal deflection ($p<0.01$).

The rate of volumetric shrinkage was highest with Heliomolar HB at 3.37% and lowest in Filtec supreme XT at 2.84%. Lee and Park (2005) reported a strong correlation between the amount of linear polymerization shrinkage and cuspal deflection. However, in the present study, there was no significant difference between the two. The reason is that the degree of shrinkage was similar among the composites examined ($p>0.01$).

In summary, the amount of cuspal deflection was lower in an incremental filled cavity than in a bulk filled cavity and the elastic modulus of the composite influenced the level of cuspal deflection.

V. Conclusion

This study investigated the amount of cuspal deflection of maxillary premolars using three different filling techniques-bulk filling, horizontal incremental two layers and three layers. The incremental filling techniques lowered the amount of cuspal deflection. The degree of cuspal deflection is dependent on the elastic modulus of the composite. Cuspal deflection was the result of an interaction between the elastic modulus of the composite and the placement technique.

Based on these findings, it is important to use an incremental placement technique to reduce the stress transferred to the tooth caused by polymerization shrinkage of the composite resin in direct resin fillings.

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국문요약

수 종의 복합 레진의 충전방법에 따른 교두 변위량 비교

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이 실험의 목적은 각각 다른 elastic modulus를 가진 4가지 복합레진을 3가지 방법 Group1-bulk filling, Group2-horizontal incremental (2 layers) filling,, Group3-horizontal incremental (3 layers)으로 수복하는 동안 나타나는 교두변위를 비교해 보는 것이었다. 총 12개 군의 교두변위를 관찰하였다. 복합레진은 Heliomolar HB (Ivoclar Vivadent, Liechtenstein), Heliomolar (Ivoclar Vivadent, Liechtenstein, Renew (Bisco Inc., Schaumburg, U.S.A). Filtec supreme XT (3M Dental Products, St.Paul, U.S.A)를 사용하였다. 각 재료의 Group 1에서는 0.15 g의 복합레진을 bulk filling으로 와동을 충전하였다. 모든 시편은 LED Curing Light (Bluephase. Ivoclar Vivadent, Liechtenstein) 를 이용하여 교합면, 근심면, 그리고 원심면에서 각각 60초씩 광중합 하였다. 각 재료의 Group 2에서는 0.07g+0.08g씩 two layers로 각 재료를 수평으로 적층충전 하였고 두 층 모두 각각 교합면, 근심면, 원심면에서 30초씩 광중합 하였고 Group 3에서는 0.05g씩 three layers로 하여 세 층 모두 위와 같은 세 면에서 20초씩 광중합 하여

총 시간은 세 군 모두 180초로 같게 하였다. 광중합 하는 동안 교두변위는 자체 제작한 교두 변위 측정 장치를 이용하여 광중합개시로부터 10분간 측정하였다. 측정값은 각 재료 안에서 Group 1, Group 2, Group 3 간의 유의차를 one-way ANOVA를 이용하여 통계 분석하였다. 또한 각각 레진은 3점 굽힘시험을 통해서 elastic modulus를 측정하였고 Acuvol (Bisco.U.S.A)를 이용하여 수축율을 측정하였다. 각 재료의 군간 차이와 탄성계수, 부피중합 수축율 간의 상관성을 Pearson's correlation analysis 이용하여 상관분석을 시행하였다. 각 재료의 Group 1 과 Group 3군 간에는 모두 통계학적으로 유의할만한 교두변위량의 차이가 있었으며 탄성계수가 제일 낮게 측정된 Heliomolar를 제외한 나머지 세 Group 에서는 Group 1 과 Group 2 간에도 통계학적으로 유의할만한 교두변위량의 감소를 나타내었다. 탄성계수측정 결과는 Heliomolar가 가장 낮은 값을 보였으며 Heliomolar HB가 가장 높은 값을 나타내었다. 수축율은 네 가지 재료간의 유의한 차이를 보이지 않았다. 상관분석 결과 재료의 탄성 계수는 교두변위량과 관계가 있었다.

본 연구에서는 적층충전이 bulk충전보다 cusp의 변위량이 적었으며 elastic modulus는 치아 교두 변위량에 영향을 준다. 레진의 중합수축에 의한 치아의 stress를 줄이기 위해서는 적층충전방법이 중요하다고 하겠다

핵심되는 말: 교두 변위, bulk filling, Incremental filling, 탄성계수, 복합레진, 중합수축