Effects of Cavity Configuration on Bond Strength and Microleakage of Composite Restoration

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국문초록

와동의 형태에 따른 복합레진의 결합강도 및 변연누출에 관한 연구

최승모 · 최기운 · 최경규 · 박상진
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복합레진의 중합시 발생하는 수축과 응력은 와동의 형태에 의하여 영향을 받으며 이는 수복재는 물론 접착계면의 물성을 결정하는 요인이 된다. 본 연구는 다양한 C-factor를 갖는 와동에 상아질 접착제 Clearfil SE Bond(Kuraray)를 도포하고 혼합형 복합레진인 Clearfil AP-X(Kuraray)와 미세혼합형의 Esthet-X(Dentsply)를 충전하여 미세인장강도 및 변연누출을 측정평가함으로써 중합수축이 수복물과 치아계면에 미치는 영향을 평가하고자 시행하였다. 98개의 Bovine 하악전치를 이용하여 표면의 상아질을 #600 SiC paper로 연마한 대조군 및 와동의 넓이를 조절하여 C-factor 2.3, 3.0, 3.7이 되도록 제작한 실험군 와동에 복합레진을 충전한 후 37 의 증류수에 24시간 보관하였다. 저속 diamond saw(Buehler)를 이용하여 1mm두께로 수직절단 후 고속 diamond point(#104 Shofu)를 이용하여 단면적 1mm^{2}가 되도록 hour-glass모양으로 형성하여 시편을 제작하였고, Universal testing machine(EZ-Test; Shimadzu, Japan)에 시편을 부착하고 cross head speed 1mm/min으로 인장력을 가하여 미세인장 결합강도를 측정하였다. 각 C-factor에 따른 변연누출실험을 위하여 복합레진이 수복된 치아를 37℃ 의 증류수에 24시간 보관한 후 와동을 제외한 부위에 nail varnish를 도포하고 3mol/L silver nitrate용액에 24시간 암보관한 다음 수세하여 현상액에 24시간 경과시킨 후 치아의 장축에 따라 절단하여 침투된 색소의 정도를 광학현미경상에서 40배로 관찰하였다. 각각의 실험결과는 ANOVA/Tukey's test 및 Kruskal-Wallis non-parametric independent analysis와 Mann-Whitney U test에 의하여 통계분석하여 다음과 같은 결론을 얻었다.

1. 대조군에 있어서 혼합형 복합레진의 미세인장 결합강도는 미세혼합형에 비하여 높았으며, 실험군 사이에는 유의차를 보이지 않았다.
2. 모든 복합레진의 미세인장 결합강도는 와동의 C-factor 증가에 따라 감소하는 경향을 나타내었고, 혼합형 복합레진의 실험군은 대조군에 비하여 낮게 나타났으며, 미세혼합형 복합레진에서는 유의차를 보이지 않았다.
3. 절단측 및 치은측 변연부의 미세누출정도는 혼합형 복합레진이 미세혼합형에 비하여 대체로 높게 나타났다.
4. 모든 실험군에서 미세누출은 C-factor 증가에 따라 증가하였고 절단측에 비하여 치은측 변연이 높게 나타났으나 통계학적 유의차는 보이지 않았다.

C-factor의 변화에 대하여 필러함량과 탄성계수가 높은 혼합형 복합레진이 미세혼합형에 비하여 더 민감한 결과를 보인다. 이는 복합레진 수복시 재료의 선택과 중합수축의 적절한 조절이 중요한 요소임을 시사한다.

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I. INTRODUCTION

One of the inevitable characteristics of dental composites is the shrinkage during radical polymerization as monomer molecules are converted into a polymer network, reducing intermolecular spaces. This shrinkage produces contraction stress in a confined structure such as a tooth cavity. The performance of a composite restoration depends upon a complete bond with the surrounding tooth structure. During placement, the polymerization contraction of the composite produces stress which can lead to failure of this bond. The majority of the contraction stress of composite occurs during the initial polymerization period after gelation, and the stress development rate decreases gradually with time[1-3]. The internal stress generated in the restricted environment of a tooth cavity can exceed the adhesive bond strength and produce a delamination of the restoration interface [4]. In cases where higher bond strength is present, this stress may cause to fracture the marginal tooth substrate and/or the composite restorative itself [5-6]. Either case results in the formation of a marginal gap, allowing the possible ingress of oral fluids and bacteria through leakage though it is not easy to clinically detect leakage around the cavity wall immediately after placement. Furthermore, marginal leakage is associated with postoperative sensitivity, and may eventually produce discoloration of the margins and/or recurrent caries, and consequently may reduce the life of a restoration.

A number of factors contribute to the magnitude of the stress produced by a given composite compositionally and technically. The amount and type of resin phase presented determines the magnitude of the polymerization contraction which occurs[7-10]. The level of inorganic filler presented directly effects the elastic modulus, translating a given amount of contraction into varying levels of stress[11]. The other approach is performed technically and includes a modified application technique[12-14], the use of a indirect restoration[15], controlling the reaction rate by altering light energy[16-18], and using flexible and low-viscosity intermediate adhesives[2,19-20]. Choi and others[21] reported the effects of adhesive thickness on polymerization contraction stress. Contraction stress decreased significantly as the adhesive thickness was increased. This stress that contributes to early marginal leakage was absorbed and relieved by increasing thickness of low-stiffness adhesive. Despite these measures, the successful use of dental composite is still hindered by its inability to reliably form well-bonded margins. Therefore, it is difficult to guarantee a leakproof restoration.

As the resin bonds to the walls and floor of the cavity preparation, competition will develop between the opposing walls as the restorative resin shrinks during polymerization[6]. The magnitude of this phenomenon depends upon the configuration of the cavity and hence is called the cavity configuration[22-24]. Cavity configuration factor(C-factor) is the ratio of the bonded surface area to the unbonded or free surface area. This ratio becomes the largest in Class I and deep Class V, that is, box-like cavities.

A micro-tensile bond test introduced recently can evaluate the bond strength between inner cavity wall and composite contrary to conventional bonding methods such as a shear bond test or a tensile bond test[25]. This testing method using small surface areas for bonding has facilitated the determination of bond strengths to caries-affected dentin[26], and dentin of cervical erosion/abrasion lesions[27].

In experimental design, maximum contraction forces were inversely related to C-factor and directly related to composite volume in a non-rigid system which allowed compliance[28]. Also, Yoshikawa and others[29] reported that the bond strength of several dentin adhesives fell as increasing C-factor by a three dimensional cavity preparation, but the difference was significant only with one adhesive system. However, there has not been reported the relationship between cavity configuration and bond strength of composite restoration directly. Therefore, the purpose of this study was to evaluate the effects of various cavity configurations on bond strength of composites and microleakage of composite restoration according to different types.

Ⅱ. MATERIALS AND METHODS

1. Specimen preparation

The materials, components, manufacturers, and batch numbers used in this study listed in Table 1. Ninety-eight bovine incisors (40 for micro-tensile test and 58 for microleakage test) within one month of extraction were selected and the pulps were cleaned from the root canals.

2. Micro-tensile test

For control group (C=1), bovine teeth were ground with wet 600 grit SiC paper serially and exposed dentin surface. In experimental groups with high C-factor, cavities were prepared with a carbide steel bur(#245; Shofu Co., Japan) in bovine teeth. The depth of cavities was 2.0mm to make even curing degree and the ratio of bonded to unbonded surface area, or the C-factor(C=1+4h/d, in which d and h are the diameter and height of the cylindrical cavities, respectively), was controlled by the diameter of cavity (Table 2). The dimensions of the preparation were verified with an electronic caliper (Mitutoyo Corp., Japan).

A self-etching primer system (Clearfil SE Bond; Kuraray Co., Japan) was applied on surface and in cavities of all specimens according to the manufacturer's instruction. The composite resins that are a hybrid (Clearfil AP- X; Kuraray Co., Japan) and a microhybrid type (Esthet-X; Dentsply, USA) were placed as a series of thin layers on the flat control surface to minimize contraction, and the cavities were bulk-filled to maximize contraction(Fig. 1; Bc and Be). Composite was light-cured (Spectrum 800; Dentsply, USA) for 40sec in all of cases. Additional composite was built-up for mounting on the micro-tensile testing zig (Fig. 1; C).

All restored specimens were stored in water at 37℃ for 24hrs and then sliced serially to be 1.0mm thick perpendicular to the bonded surfaces with a low-speed diamond saw (Isomet; Buehler, USA) under copious water supply. Slices were trimmed into an hour-glass shape with the narrowest portion of approximately 1mm^2 area located at the adhesive-dentin interface using with a diamond point (#104, Shofu, Japan) in high -speed handpiece (Fig. 1-F). The trimmed specimens were mounted on a testing zig with cyanoacrylate adhesive (Zapit, MDS Products Co., Corona, USA)(Fig. 2), then stressed to failure in tension at 1mm/min in a universal testing machine (EZ test; Shimadzu, Japan).

The maximum tensile force was divided by the area of the specimen and the measured micro-tensile bond strength values were analysed using ANOVA/Tukey's test at a significance level of 0.05.

Table 1. The materials used in this study

Materials(batch No.)	Main components	Manufacturer
Clearfil SE Bond		
Primer(00184A)	MDP, HEMA, water	Kuraray Co.
Adhesive(00175A)	MDP, dimethacrylate, HEMA, microfiller	(Osaka, Japan)
Clearfil AP-X(0526A)	Barium glass, silicone dioxide	Kuraray Co.
- *Hybrid type*	3.0㎛(0.1-15㎛), 84.5wt%	(Osaka, Japan)
Esthet-X(530059)	BAFGs*; 0.6-0.8㎛(0.02-2.5㎛), silicone-	Dentsply
- *Microhybrid type*	dioxide nanofiller; 0.01-0.02㎛, 77wt%	(Milford, USA)

*BAFGs : Bariumalumino fluorosilicate glass

3. Microleakage Test

Each cavity was prepared and restored with composites as same manner in micro-tensile test, but control group was ruled out. All filled restorations were finished immediately using abrasive disks (Soflex, 3M, USA). After finishing, the teeth filled with composites were placed in 37℃ water for 1 day. The teeth were then coated with nail varnish 2.0mm short of the restoration margins after the apices were blocked with utility wax. These measures were taken to prevent staining from occurring through any route besides that provided by the presence of marginal defects.

As described in a previous study[21], the teeth were stained by immersion in room temperature 3mol/L silver nitrate in amber vials for 24 hours in a dark room. They were then removed, rinsed with tap water, and placed in film developer (Eastman Kodak) under fluorescent light for 24 hours. The roots were cut off and embedded in epoxide resin (Buehler, USA) and allowed to set overnight before they were sectioned inciso-gingivally in the approximate center of the restoration with a low-speed saw. After the sectioned surface was ground with 400 and 600 grit SiC paper and polished with 3㎛ diamond compound (Buehler), both surfaces were examined under a stereomicroscope (Olympus, Japan) at x40 magnification by two examiners. Each examiner independently graded the dye penetration at the incisal and gingival margin using the following ordinal scale:

0 = no marginal leakage.
1 = silver nitrate penetration that extended less than or up to half the distance to the DEJ (dentino-enamel junction).
2 = penetration greater than half and up to, but not past, the DEJ.
3 = penetration past the DEJ, but not including the pulpal wall.
4 = penetration involving the pulpal wall.

Table 2. Experimental groups

Groups (code)	Configuration of bonding substrate
C=1 (C)	ground dentin surface
C=2.3 (C2)	cavity (depth: 2mm, diameter: 6mm)
C=3.0 (C3)	cavity (depth: 2mm, diameter: 4mm)
C=3.7 (C4)	cavity (depth: 2mm, diameter: 3mm)

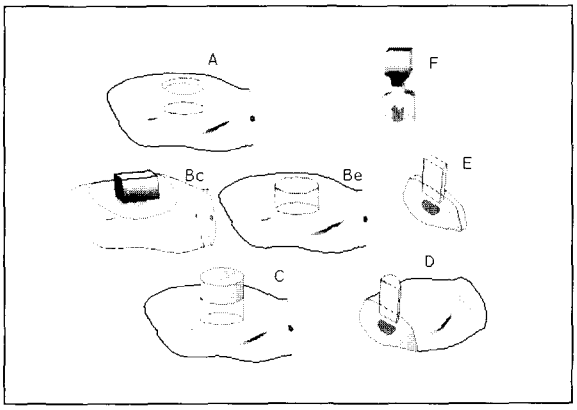

Fig. 1. Specimen preparation for tensile bonding test: A) cavity preparation for each C-factor, Bc) composite bonding on dentin surface for control group, Be) composite filling for experimental groups, C) additional composite build- up, D-E) vertical slices (1.0mm thick) cut perpendicular to the long axis of the tooth, and F) trimmed specimens into hour-glass shape with the narrowest portion.

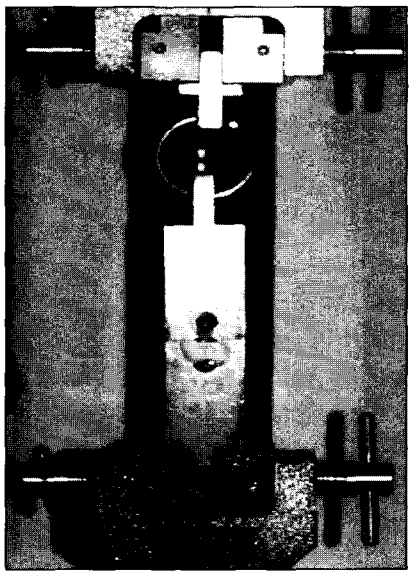

Fig. 2. Micro-tensile bond test.

Two examiners reevaluated all specimens if there were any discrepancies. The statistical analysis of the results of the staining measurement was done with the Kruskal- Wallis non-parametric independent analysis and the Mann-Whitney U test to evaluate differences between experimental groups at a significance level of 0.05.

Ⅲ. RESULTS

1. Micro-tensile test

Micro-tensile bond strengths are summarized in Table 3, and those of each type composite are showed in Fig. 3 and 4. Mean micro-tensile bond strength was decreased with increasing C-factor in both types of composites. For hybrid composite, the tensile bond strength to flat dentin showed the greatest value of approximately 37MPa and was different significantly from experimental groups with higher C-factor statistically. And there was no significant difference among these groups. For microhybrid composite, tensile bond strengths were decreased with increasing C-factor though no difference statistically. Tensile bond strength between hybrid and microhybrid type composites with various C-factors is also compared in Fig. 5.

2. Microleakage test

Microleakage scores of all experimental groups are shown in Table 4. No specimens ranked zero in the

Table 3. Micro-tensile bond strength (MPa SD)

Groups	Hybrid composite	Microhybrid composite
C	36.88±4.70[a]	25.68±7.94
C2	23.65±2.42[b]	23.72±6.19
C3	25.01±9.04[b]	22.48±7.96
C4	18.03±10.93[b]	21.03±6.08

Groups designated with different superscript letters are significantly different ($p<0.05$).

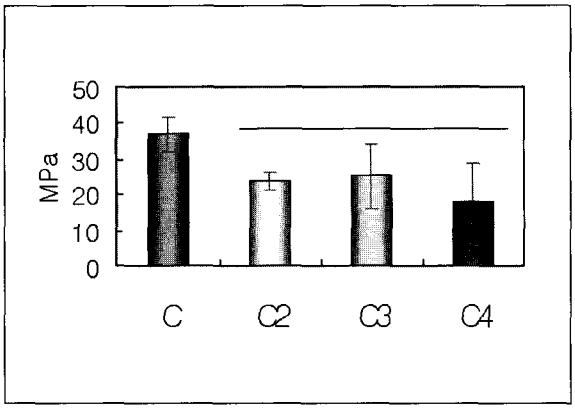

Fig. 3. Micro-tensile bond strength of hybrid type composite according to C- factors.

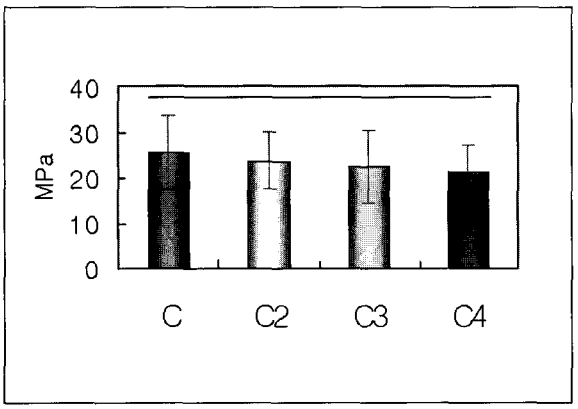

Fig. 4. Micro-tensile bond strength of microhybrid type composite according to C-factors.

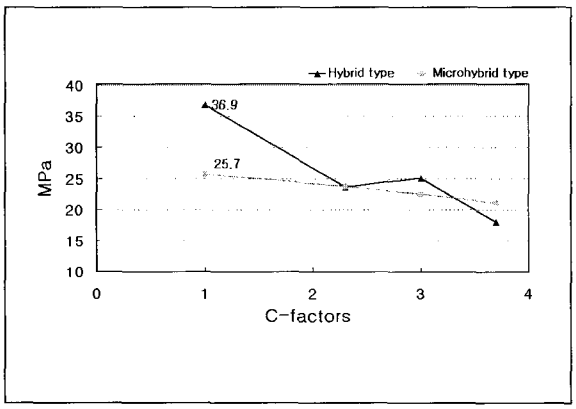

Fig. 5. Comparison of micro-tensile bond strength between hybrid and microhybrid type composites.

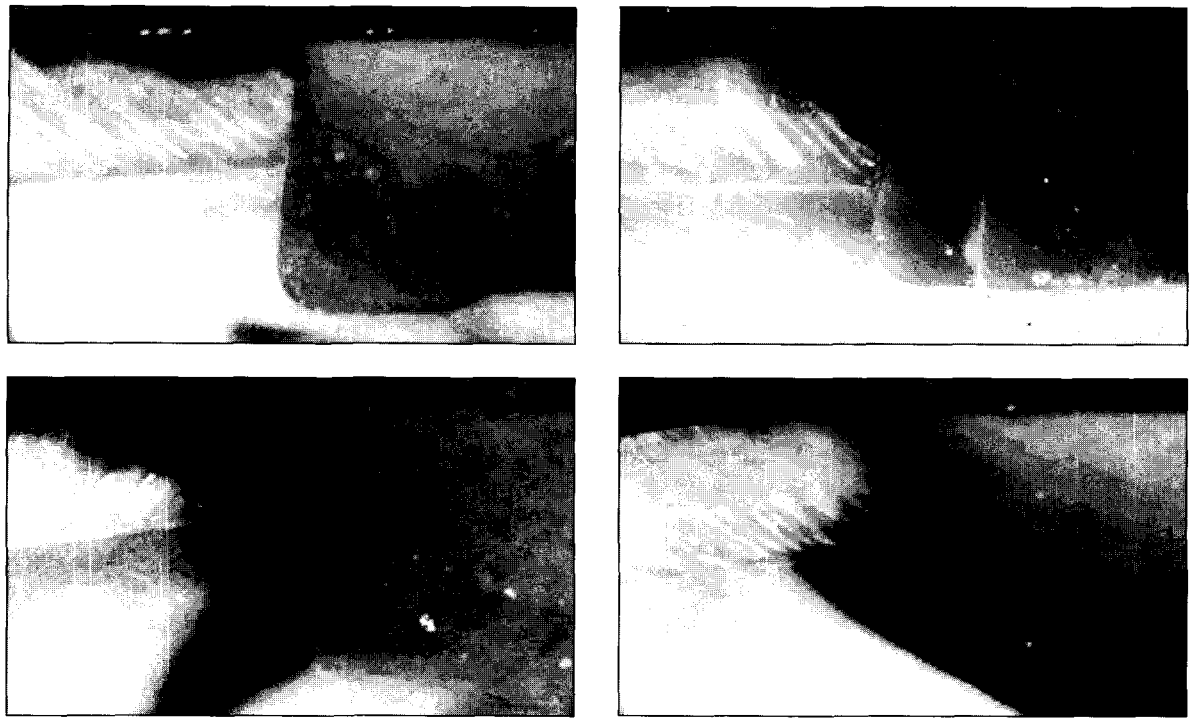

Fig. 6. Degree of microleakage. (a); degree 1, (b); degree 2, (c); degree 3, (d); degree 4.

Table 4. Microleakage scores of experimental groups

Groups	Margin(n)	Clearfil AP-X						Esthet-X					
		0	1	2	3	4	mean	0	1	2	3	4	mean
C2	Incisal (12)	0	5	4	3	0	1.83	0	4	7	1	0	1.75
	Gingival (12)	0	1	5	6	0	2.42	0	2	7	1	2	2.25
C3	Incisal (9)	0	3	0	6	0	2.22	0	3	2	4	0	2.11
	Gingival (9)	0	3	0	6	0	2.33	0	1	3	4	1	2.56
C4	Incisal (8)	0	1	2	4	1	2.63	0	0	4	4	0	2.50
	Gingival (8)	0	1	1	4	2	2.88	0	0	3	4	1	2.75

microleakage experiment. Microleakage scores of hybrid composite restoration were generally higher than those of microhybrid at both incisal and gingival margin ($p>0.05$). In all experimental groups, microleakage scores were increased with higher C-factors, and those of gingival margin were higher than incisal margin though there were no difference significantly($p>0.05$). Figure 6 showed the microleakage at each score mentioned previously.

Ⅳ. DISCUSSION

Though the use of composite restoration is increasing continuously and most dentists select composites as their main esthetic alternatives to amalgam for posterior teeth, approximately 70% continue to use amalgam as their primary

posterior restorative[30]. Composites are more difficult to place and their longevity is inferior to that of amalgams in general practice[31]. Secondary or recurrent caries that is regarded as a main cause of failure

is primarily related to technical difficulties in placing restorations with sealed margins due to the excessive polymerization contraction of composites. Many factors influence marginal leakage in composite restorations, including polymerization contraction and differences in thermal expansion characteristics[32]. Either can produce stress within the composite when it is restrained from shrinking freely. Anything that increase the capacity of the resin to flow and relieve stress, such as large unbonded surfaces, slow curing rates, or porosity, results in less contraction stress [1,6,23,33].

In previous pilot study, we have used the sand-blasted and silanated pyrex tube to make simulated cavity on dentin surface instead of tooth cavity in this study. However, there was no significant difference with increasing the C-factors. It was difficult to get the attachment between tube and dentin surface and the pyrex tube was too flexible to keep constant configuration. This is why the previous study was failed. In virtue of microtensile testing method, we can evaluate the bond strength on irregular tooth surface as well as on inner surface of cavity wall, which could not be conducted with the conventional testing method that was mainly shear bond test. Moreover, microtensile test has some other advantages that can evaluate more adhesive failures, means and variances can be calculated for single tooth, permits measurements of regional bond strengths on very small areas, and facilitates SEM examination of the failed bonds. On the other hand, there are some disadvantages that is labor-intensive, technically demanding, difficult to measure bond strength under 5MPa and require special equipment [34].

Mean tensile bond strength of hybrid composite was decreased so much in lower C-factor, but that of microhybrid was slightly decreased with C-factors. This result suggests that the bond strength of a stiffer composite is more affected and impaired by the cavity configuration. Most of hybrid composites have the higher elastic modulus, that is, high stiffness as a result of a higher filler load than a microhybrid [35]. For hybrid composite, the tensile bond strength of a control group to flat dentin surface was the highest value because there was no or less impairment by contraction stress for polymerization.

Another reason that we can suppose, which the composite with higher physical properties is generally showed the higher bond strength to tooth substrate. Miyazaki et al[36] reported that filler content was one of the important factors influencing the physical properties of composites in the study of bond strength to bovine dentin. Another researches informed us that mechanical properties of dental composites were most highly correlated with bond strengths to the tooth dentin/ or enamel[37,38].

Stresses large enough to exceed the adhesive forces between the tooth and the composite are relieved as gaps formed at the margins [6,32]. Because the bonding of resin to dentin is more variable than to enamel in vivo, cavities with margins in dentin are most at risk [39]. Optimization of these margins depends on reducing contraction or relieving contraction stresses. In this study, microleakage scores of hybrid composite restoration were generally higher than those of microhybrid at both incisal and gingival margin though there were no significant differences. In all experimental groups, microleakage scores were increased with higher C-factors, and those of gingival margin were higher than incisal margin though there was no significant difference. Similar microleakage test according to various C-factors was performed by Choi et al[21] previously. Although the clinical results are unpredictable under the environment that C-factor is less than 1, microleakage at the increased C-factors showed a relative high scores in this study.

Beside of this study, we have performed another research[40] having a hypothesis that contraction stress may affect the properties of composite restoration itself. The properties of hybrid composite were more deteriorated with increasing C-factor than that of microhybrid type. There was performed another study that C-factor had no influence on the cavity adaptation for compomer restorations[41]. This might be due to reduced stress generation at the bonding interface caused by relatively low mechanical properties immediately after curing, less elasticity, and water absorption in compomers.

Hybrid composite with higher filler contents and elastic modulus showed more sensitive results than microhybrid according to increasing C-factor. These results suggest that the adequate selection of materials as well as the control of polymerization contrac-

tion stress is so important factors for successful composite restoration. We have a plan to study continuously on human teeth with same protocol instead of bovine teeth in the future and need to evaluate the correlation between these vitro studies and clinical situations through the examination of practical restorations in oral cavity of the followed patient up for long time.

Ⅴ. CONCLUSION AND SIGNIFICANCE

Polymerization contraction depends upon the type of dental composites and the cavity configuration that plays an important role on the development of its stresses. The purpose of this study was to evaluate the effects of various cavity configurations on bond strength of composites and microleakage of composite restoration according to different resin types.

1. Micro-tensile bond strength of hybrid composite to flat dentin surface was significantly higher than that of microhybrid type($p<0.05$), but there was no significant difference between experimental groups of two type composites.
2. Micro-tensile bond strength was decreased with increasing C-factor in both types of composite. For hybrid composite, the tensile bond strength to flat dentin showed significantly different from experimental groups with higher C-factor. And there was no significant difference in microhybrid composite.
3. Microleakage scores of hybrid composite restoration were generally higher than those of microhybrid at both incisal and gingival margin($p>0.05$).
4. In all experimental groups, microleakage scores were increased with higher C-factors, and those of gingival margin were higher than incisal margin though there was no significant difference($p>0.05$).

Hybrid composite with higher filler contents and elastic modulus showed more sensitive results than microhybrid with increasing C-factor. These results suggest that the adequate selection of materials as well as the control of polymerization contraction stress are so important factors for successful composite restoration.

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