

Effects of direct and indirect bonding techniques on bond strength and microleakage after thermocycling

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Objective: The purpose of this study was to compare the shear bond strength (SBS) of brackets and microleakage of a tooth-adhesive-bracket complex bonded with a direct and an indirect bonding technique after thermocycling. **Methods:** Fifty non-carious human premolars were divided into two equal groups. In the direct bonding group a light-cured adhesive and a primer (Transbond XT) was used. In the indirect-bonding group, a light-cured adhesive (Transbond XT) and chemical-cured primer (Sondhi Rapid Set) were used. After polymerization, the teeth were kept in distilled water for 24 hours and thereafter subjected to thermal cycling (500 cycles). For the microleakage evaluation, 10 teeth from each group were further sealed with nail varnish, stained with 0.5% basic fuchsin for 24 hours, and examined under a stereomicroscope. Fifteen teeth from each group were used for SBS testing with the universal testing machine and adhesive remnant index (ARI) evaluation. Data were analyzed using the Mann-Whitney U test, Chi-square test, and Fisher's exact test. **Results:** There were no statistical differences on SBS and microleakage between the two bonding techniques. The indirect bonding group had a significantly lower ARI score. Bracket failures were obtained between enamel-resin interfaces. **Conclusions:** The type of bonding technique did not significantly affect the amount of microleakage and SBS. (Korean J Orthod 2009;39(6):393-401)

Key words: Indirect bonding, Microleakage, Shear bond strength, ARI score

INTRODUCTION

The use of phosphoric acid to adhere acrylic materials to enamel was first introduced by Buonocore.¹ In 1964, Newman² described bonding of orthodontic attachments to the etched enamel surface with epoxy-derived resin. In orthodontic practice, brackets can be

bonded directly or indirectly. There are some inherent shortcomings with the direct bonding technique, including poor visualization of posterior teeth, greater possibility of moisture contamination, and increased doctor chair time. In 1972, Silverman and Cohen³ introduced the indirect bonding technique to place brackets on teeth more accurately and efficiently in the clinic. This technique involves a two-stage process of bracket placement in the laboratory on a plaster model and transfer of these attachments to the patient's mouth by means of a tray, where they are bonded to the etched enamel surface. Most current indirect bonding techniques are based on a method described by Thomas.⁴

Initially, bond failure rates for indirect bonding (13.9%) were higher when compared with direct bonding (2.5%). However, with modifications and improvements to the technique, the two systems now have similar bond strengths and failure rates.⁵⁻⁷ Linn et al.⁸

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compared the shear bond strength (SBS) and the sites of bond failure for brackets bonded to teeth between the direct bonding technique (Transbond XT) and indirect bonding technique (Transbond XT/Sondhi Rapid Set). The study showed that reduction of SBS was also observed in the indirect bonding technique group; and there were no statistically significant differences between the two techniques. When the Adhesive Remnant Index (ARI) was determined, the indirect bonding technique was found to have a significantly lower ARI score. There was no strong correlation between SBS and ARI scores. Hocevar and Vincent⁷ reported that 44% of direct-bonded brackets fractured at the bracket-adhesive interface, whereas 72% of the indirect-bonded brackets failed at the adhesive-enamel interface. Daub et al.⁹ evaluated the SBS of one direct (Group 1 - Transbond XT) and two indirect bonding (Group 2 - Transbond XT/Sondhi Rapid Set, Group 3 - Enlight LV/Orthosolo) methods/adhesives after thermocycling. Each sample was thermocycled between 5°C and 55°C for 500 cycles. The mean SBS in Group 1, 2 and 3 were not statistically significantly different. The authors also determined the ARI scores and found that Group 2 had a significantly higher percentage of bond failures at the adhesive-enamel interface.

The polymerization shrinkage of the adhesive material may cause gaps between the adhesive material and enamel surface and contribute to microleakage, permitting the passage of bacteria and oral fluids, which may initiate white spot lesions under the bracket surface area.¹⁰ Polymerization shrinkage also varies from composite to composite and depends on the percentage of filler, the diluents, and the percentage of monomer conversion in the specific composite resin.¹¹

From an orthodontic point of view, microleakage may lead to lower clinical SBS and white spot lesions.¹⁰ Arhun et al.¹⁰ showed that metal brackets cause more microleakage compared with ceramic brackets. Ulker et al.¹² compared the microleakage of the brackets bonded with high-intensity light curing lights and conventional halogen lights. This study showed that high-intensity curing units did not cause more microleakage than conventional halogen lights.

There have been no studies that investigated the effects of different bonding techniques on microleakage.

The purpose of this study was to evaluate the SBS, the mode of bond failure, and microleakage of direct and indirect bonding techniques after thermocycling.

MATERIAL AND METHODS

Fifty human maxillary premolars, extracted for orthodontic reasons at the Cumhuriyet University, Faculty of Dentistry, with no decay, restorations, or surface defects, were collected. After extraction, the teeth were stored in 0.5% chloramines T solution for one week and transferred to distilled water. The teeth were stored in distilled water at room temperature until the experiments took place (a maximum of 4 months). They were randomly separated into two groups of 25. Immediately before bonding, the teeth were prepared by removing soft-tissue remnants, calculus and plaque and mounted in cold-cure acrylic in groups of five with interproximal surfaces of adjacent teeth in contact. All teeth were bonded using a Mini Master upper bicuspid bracket (American Orthodontics, Sheboygan, WI, USA) with a projected base surface area of 10.25 mm². The whole laboratory process was performed by the same author (Öztürk F) with 6 years of experience.

In the direct bonding group, teeth were bonded directly according to the manufacturer's recommendations using a light-cured adhesive and primer (Transbond XT, 3M Unitek, Monrovia, CA, USA). In the indirect bonding group, teeth were bonded indirectly with light-cured adhesive (Transbond XT) and a filled resin primer (Sondhi Rapid Set A/B Primer, 3M Unitek, Monrovia, CA, USA).

The surface of each tooth was polished for one minute using a combination of a polishing agent and a brush at a low speed. A 37% phosphoric acid gel (3M Dental Products, St Paul, MN, USA) was used for acid etching for 30 seconds. The teeth were rinsed with water for 30 seconds and dried with an oil-free source for 20 seconds. In all etched cases, the frosty white appearance of the etched enamel was apparent.

For the direct bonding group, the brackets were bonded by the direct method, one at a time. A thin layer of Transbond XT light-cured primer was applied to the tooth, Transbond XT adhesive was applied to the bracket base, and the bracket was pressed lightly

in the desired position onto the tooth. The bracket was placed in the center of the crown, with the center of the bracket over the long axis of the tooth. The excess adhesive was removed with a hand instrument, and the bracket was cured with plasma arc curing light (Apollo 95E, Denmed Technologies, Inc, Westlake Village, CA, USA) for 3 seconds from the mesial side and 3 seconds from the distal.

In the indirect bonding group, alginate impressions were taken, and hard-stone working models were obtained. Two coats of Al-Cote separating medium (Dentsply International Inc, York, PA, USA) were painted on the models and allowed to dry. Transbond XT adhesive was applied to the bracket base, and the bracket was pressed lightly in the desired position onto the cast. The bracket was placed in the center of the crown, with the center of the bracket over the long axis of the tooth. The excess adhesive was removed with a hand instrument, and the bracket was cured with a plasma arc curing light for 15 seconds from the mesial and 15 seconds from the distal. This extended curing period was chosen to achieve complete polymerization of the adhesive on the plaster model.^{13,14} Before forming the indirect bonding trays, the undercut areas, such as hooks, were blocked out with a soft transparent silicone (Emiluma, Ortho Kinetics, Vista, CA, USA) for indirect bonding. After the silicone hardened, transfer trays were made from 0.040-inch (1 mm) vacuum-formed essix (Raintree Essix Inc., Los Angeles, CA, USA). After the transfer tray material had set, the specimens were soaked in water for 20 minutes to dissolve the separating medium. The transfer tray was removed, and the adhesive bases were gently sandblasted avoiding any disturbance in the base resin, washed, and dried as advised by Sondhi.¹⁵ A thin layer of primer A (Sondhi Rapid Set, 3M Unitek, Monrovia, CA, USA) was painted on each tooth and a thin layer of resin B (Sondhi Rapid Set, 3M Unitek, Monrovia, CA, USA) was painted on each bracket's adhesive base. The transfer tray was placed on the experimental tooth and held with finger pressure for 30 seconds and then left on the teeth without any pressure for two minutes before removal of the tray.

Teeth were stored at 37°C in distilled water for 24 hours. After 24 hours, the samples were thermocycled

according to the ISO 11405 recommendation.¹⁶ Each specimen underwent 500 complete cycles in distilled water between 5°C and 55°C, with a dwell time of 30 seconds in each bath and a transfer time of 15 seconds between baths.

After thermocycling was applied, 10 teeth of each group were used for evaluation of the microleakage and 15 teeth were used for the evaluation of the SBS and ARI score.

Evaluation of shear bond strength and adhesive remnant index

The teeth were removed from the acrylic block after bonding and embedded in phenolic rings using autopolymerizing polymethyl methacrylate. A mounting jig was used to align the facial surface of the tooth to be perpendicular to the bottom of the mold and its labial surface parallel to the force during the SBS test. A universal testing machine (LF Plus, Ametek LLOYD Instruments, West Sussex, England) was used for the shear bond test at a crosshead speed of 0.5 mm/min. The standard knife-edge was positioned to make contact between the tie wing and the bracket base as close to the base as possible and directed parallel to the long axis of the crown of the tooth. The load at failure was recorded by a personal computer connected to the test machine. SBS values were calculated as the recorded failure load divided by the surface area (bracket base) and expressed in megapascals (MPa).

After debonding, the enamel surface of each tooth and the bracket bases were examined under 10 X magnification with a stereomicroscope (SMZ 800, Nikon, Tokyo, Japan). ARI scores¹⁷ were assigned to each specimen. An ARI score of 0 indicated that no adhesive was left on the tooth in the bonded area; 1 indicated that less than half of the adhesive was left on the tooth; 2 indicated that more than half was left on the tooth; and 3 indicated that all the adhesive remained on the tooth, with a distinct impression of the bracket mesh. Examples of assignments of ARI scores are shown in Fig 1.

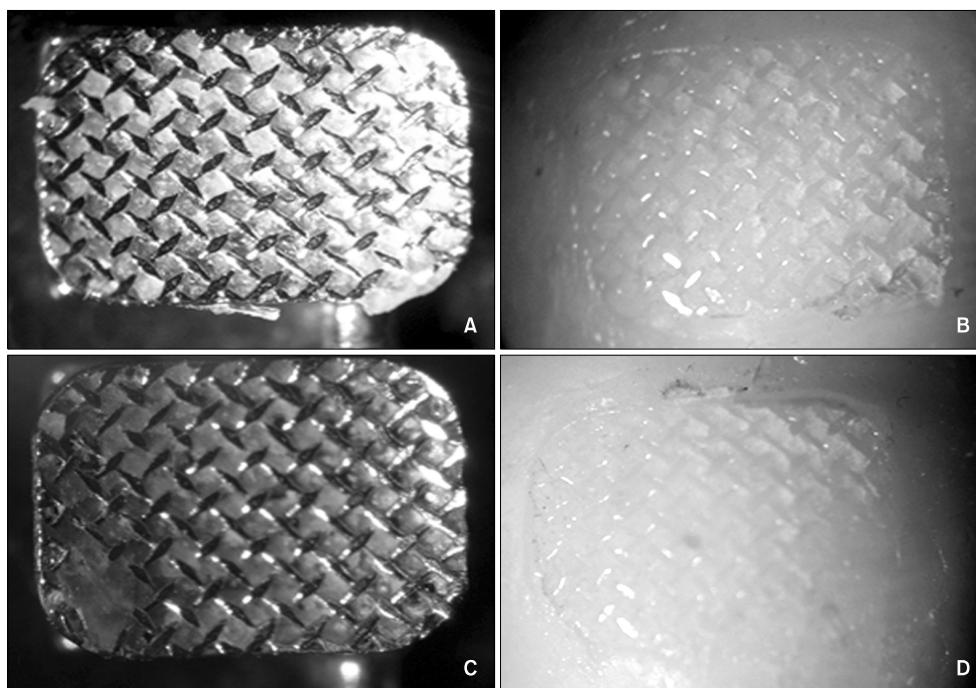


Fig 1. Examples of assignments of adhesive remnant index scores (with 10 × magnification). **A, B**, ARI score of 3 indicated that all the adhesive remained on the tooth; **C, D**, ARI score of 2 indicated that more than half was left on the tooth.

Microleakage evaluation

Two consecutive layers of nail varnish were applied to the entire surface of the tooth, except for an area of approximately 1 mm away from the brackets. The teeth were immersed in 0.5% solution of basic fuchsin for 24 hours at room temperature. After rinsing with distilled water, the samples were air-dried and each specimen was sliced longitudinally with a low-speed diamond saw (Isomet, Buehler, Lake Bluff, IL, USA) under water coolant in the buccolingual direction. All sections were examined by two calibrated investigators with a stereomicroscope (30 X magnifications) for dye penetration. Each section was scored from both the occlusal and gingival margins of the brackets between the bracket-adhesive and the adhesive-enamel interfaces. Scoring was made according to the following criteria:

Score 0: No dye penetration between the bracket-adhesive or adhesive-enamel interface.

Score 1: Dye penetration restricted to 1 mm of the bracket-adhesive or adhesive-enamel interface.

Score 2: Dye penetration into the inner half (2 mm) of the bracket-adhesive or adhesive-enamel interface.

Score 3: Dye penetration into 3 mm of the bracket-adhesive or adhesive-enamel interface.

In cases of disagreement between scoring, consensus was obtained by using the greater score. Fig 2 demonstrates individual examples of scoring.

Statistical analyses

The data was analyzed using SPSS for Windows, version 14.0 (SPSS Inc., Chicago, IL, USA).

The assessments of SBS data were analyzed using the Mann-Whitney U test. ARI and microleakage scores were evaluated with the Chi-square test, and Fisher's exact test. Also, the relationship among SBS Data, ARI, and microleakage scores was analyzed with correlation analysis. The level of significance was set at $p < 0.05$.

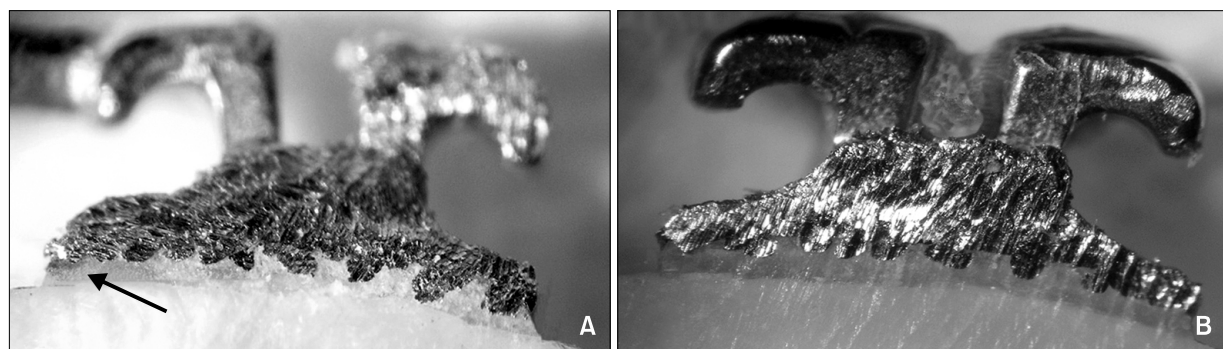


Fig 2. Microleakage evaluation between the bracket-adhesive and the adhesive-enamel interfaces. **A**, A specimen bonded with the direct bonding technique (30 × magnification). The adhesive-tooth interface scores are 0 for both gingival and occlusal sides. For the adhesive-bracket interface, scores are 0 for the occlusal side and 1 for the gingival side; **B**, a specimen bonded with the indirect bonding technique (30 × magnification). No microleakage found under the bracket.

Table 1. Comparison of the shear bond strength (SBS) and the adhesive remnant index (ARI) score between direct and indirect bonding groups

		Direct bonding (n = 15)	Indirect bonding (n = 15)	Significance
SBS value (MPa)		12.69 ± 3.53	11.43 ± 3.63	NS
ARI score	0	6.7%	40.0%	$\chi^2 = 12.45$ $p = 0.006$
	1	20.0%	46.7%	
	2	33.3%	13.3%	
	3	40.0%	—	

NS, Not significant. The SBS values were analyzed using the Mann-Whitney U test and ARI scores were evaluated with the Chi-square test ($p < 0.05$). ARI scores: 0, no adhesive left on the tooth; 1, less than half of the adhesive left on the tooth; 2, more than half of the adhesive left on the tooth; 3, all adhesive left on the tooth.

RESULTS

The mean SBS and standard deviation values are shown in Table 1. Brackets directly bonded with Transbond XT showed mean bond strength of 12.69 ± 3.53 MPa. Brackets bonded indirectly and chemically cured had a mean SBS of 11.43 ± 3.63 MPa. There were no statistical differences between two groups ($p > 0.05$).

The ARI scores are given in Table 1. Comparisons

of resin remnants between two groups showed statistically significant differences ($p < 0.05$). The ARI scores showed that the indirect bonding group had significantly higher percentage of bond failures at the adhesive-enamel interface.

The comparison of microleakage scores between occlusal and gingival sides for enamel-adhesive and adhesive-bracket interfaces are shown in Table 2. Statistical comparisons of the microleakage scores showed no significant differences between two groups ($p > 0.05$).

Microleakage scores among the groups showed that the direct bonding group had statistically higher microleakage scores in the enamel-adhesive interface at the gingival side ($p < 0.05$).

On the basis of the results of the correlation analysis, in the direct bonding group, there was an adverse relationship between ARI scores and SBS values ($r = -0.78$). The quantity of this relationship is significantly important ($p < 0.05$). It is observed that as the ARI scores increase, the SBS values decrease. Correlation analysis showed that there was no relationship between microleakage scores and SBS values in the direct bonding group. In the indirect bonding group, an adverse relationship was found between SBS and microleakage scores at the adhesive-bracket interface, both occlusal ($r = -0.64$) and gingival margins ($r = -0.68$). The quantity of this relationship is significantly important ($p < 0.05$). When the microleakage scores between the adhesive and the bracket

Table 2. Comparison of microleakage scores between bracket - adhesive surfaces and adhesive - enamel surfaces from occlusal-gingival sides

		Bracket-adhesive interface			Adhesive-enamel interface		
		Direct bonding (n = 10)	Indirect bonding (n = 10)	Sig	Direct bonding (n = 10)	Indirect bonding (n = 10)	Sig
Occlusal scores	0	80%	60%	NS	90%	70%	NS
	1	20%	40%		10%	20%	
	2	—	—		—	10%	
	3	—	—		—	—	
Gingival scores	0	40%	40%	NS	30%	20%	NS
	1	60%	60%		60%	50%	
	2	—	—		10%	30%	
	3	—	—		—	—	

NS, Not significant; microleakage scores: Score 0, no dye penetration between the bracket-adhesive or adhesive-enamel interface; Score 1, dye penetration restricted to 1 mm of the bracket-adhesive or adhesive-enamel interface; Score 2, dye penetration into the inner half (2 mm) of the bracket-adhesive or adhesive-enamel interface; Score 3, dye penetration into 3 mm of the bracket-adhesive or adhesive-enamel interface.

interface increase (both occlusal and gingival), the SBS values decrease. According to the correlation analysis there were no relationship between ARI scores and SBS values in the indirect bonding group.

DISCUSSION

This study compared the SBS, mode of bond failure (ARI), and microleakage of direct and indirect bonding techniques after thermocycling.

The results from this study showed that there were no significant differences in shear bond strength between direct and indirect bonding techniques. Reynolds and von Fraunhofer¹⁸ indicated that to overcome normal orthodontic forces shear bond strengths should be in the range of 5.9 to 7.9 MPa. The mean SBS in this study was 12.69 ± 3.53 MPa for direct bonding and 11.43 ± 3.63 MPa for the indirect bonding group. The SBS values of both groups were over this clinically acceptable range.

Several studies compared the SBS of direct and indirect bonding methods. Polat et al.¹⁹ showed that there were no statistically differences between the direct bonding group (Transbond XT) and indirect bonding Group I (Therma Cure/Custom IQ), whereas both yielded significantly higher SBS values compared with the indirect bonding Group II (Transbond XT/Sondhi

Rapid Set) in vitro. In the in vivo parts of the same study, failure rates of the brackets were followed after nine months and there were no differences found between the two indirect bonding groups. Klocke et al.²⁰ showed that there were no significant differences in SBS between the indirect bonding groups (Transbond XT/Sondhi rapid set and Phase II/Maximum cure) and direct bonding group (Transbond XT). The bond strength of thermally cured indirect bonding group (ThermaCure), however, was significantly lower. Yi et al.²¹ found no statistically significant differences in SBS between indirectly bonded brackets (Transbond XT and sondhi rapid set) and light-cured directly bonded brackets (Transbond XT). In these previous studies, samples were not thermocycled. Orthodontic adhesives are routinely exposed to temperature variations in the oral cavity. Air temperature, humidity, and air velocity when breathing can also alter resting mouth temperature. Bishara et al.²² have suggested that thermal cycling should be a part of the testing protocol of new adhesives. Daub et al.⁹ compared the shear bond strengths of direct bonding (Transbond XT) and indirect bonding (Transbond XT/Sondhi Rapid Set) techniques after thermocycling. Their study showed that there were no statistically significant differences between the two techniques.

Previous studies in which samples were nonther-

mocycled showed that the indirect bonding method had significantly lower ARI scores than the direct bonding method.^{7,8,23} Daub et al.⁹ also showed that there was no statistically significant difference in the location of bond failure in the direct bonding (Transbond XT) and light-cured indirect bonding (Enlight LV/Orthosolo) groups after thermocycling. Based on their findings, the chemical-cured indirect bonding group (Transbond XT/Sondhi Rapid Set) was statistically different from the direct bonding and the light-cured indirect bonding groups after thermocycling. In accordance with these studies, our study showed significantly higher bond failure rates at the adhesive-enamel interface in the indirect bonding group. This reduced remnant resin on the tooth is clinically desirable because it requires fewer cleanups on debonding and reduces the risk of enamel damage.²³

The difference of our study from similar previous studies is the evaluation of microleakage. The potential of white spot lesion formation around orthodontic brackets has become a particular clinical problem for orthodontic treatment. Microleakage is the seeping and leaking of fluids and bacteria between the tooth and restoration in restorative dentistry. James et al.¹¹ were the first to point out the increased risk of decalcification caused by microleakage around orthodontic brackets. Both the area around the brackets and the area under the brackets need attention to determine the risk of caries formation.

Different techniques have been introduced to assess microleakage around restorations in dentistry. In the present study, microleakage of the bonded specimens was determined by the dye penetration method, which is one of the most common microleakage assessment methods.^{12,24-27} We used plasma arc curing light and Transbond XT adhesive in both groups. James et al.¹¹ showed that there were significant differences in microleakage among plasma arc light, argon laser, and conventional halogen light when the adhesive pre-coated (APC) adhesive system was used. However, there was no significant difference in microleakage between groups when the Transbond XT adhesive system was used. In the current study microleakage was examined using specimens that were sliced longitudinally. Although we did not find any significant differences

between microleakage scores, these specimens may not represent the whole enamel-adhesive-bracket interface. This status was a limitation of our study and in a future project we will try to overcome this problem. Ulker et al.¹² showed that the type of light-curing unit (plasma arc curing light, light-emitting diode, and conventional halogen light) did not significantly affect the amount of microleakage.

The type of the bonding technique did not significantly affect the amount of microleakage at the gingival or occlusal margins of the adhesive-enamel and adhesive-bracket interfaces according to our results. Studies in restorative dentistry have demonstrated that curing composites causes polymerization shrinkage and microleakage.^{28,29} Polymerization shrinkage also varies from composite to composite and depends on the percentage of the filler, diluents, and monomer conversion in the specific composite resin and the photopolymerization type.³⁰ In restorative dentistry, composite resin is placed in the cavity in large amounts, and curing can create excessive shrinkage and gap formation. In contrast, orthodontic adhesive layers are very thin, and there is some adhesive at the edges of the bracket to absorb some shrinkage. Because the bracket is free floating, the shrinkage can pull the bracket closer to the enamel.³¹ Therefore, polymerization shrinkage and subsequent microleakage is less important in orthodontic applications than it is in restorative dentistry.¹¹

Ramoglu et al.²⁵ observed higher microleakage scores at both adhesive interfaces at the gingival sides for all specimens, which were cured with resin-modified glass ionomer or conventional resin. In this study, although there were higher microleakage scores found at the gingival side between both interfaces, there was a statistically significant difference in microleakage scores only between adhesive-tooth interfaces at the gingival side in the direct bonding group. Arhun et al.¹⁰ and Ramoglu et al.²⁵ attributed these differences to surface curvature anatomy, which may result in relatively thicker adhesive at the gingival margin.

Factors such as the adhesive system, composite composition, photopolymerization type, and exposure time affect the bond strength of brackets. In restorative dentistry literature, it was established that durability of

bond strength could be affected by microleakage.^{32,33} When we look from the orthodontic perspective; in the case of microleakage occurring on the adhesive-tooth interface, there is a risk of formation of a white spot lesion, and in the case of microleakage occurring on the adhesive-bracket interface, bracket failure probability may increase due to bond degradation.³⁴ Although James et al.¹¹ could not demonstrate any correlation between microleakage and bond strength, Arhun et al.¹⁰ reported that metal brackets cause more leakage between the adhesive-bracket interface than ceramic brackets, which may lead to lower clinical SBS and white spot lesions. Our study showed that there is an adverse relationship between SBS and microleakage at the occlusal and gingival side between adhesive-bracket interfaces in the indirect bonding group.

CONCLUSION

This study showed that indirect bonding and direct bonding techniques produce clinically acceptable bond strengths. The type of the bonding technique did not significantly affect the amount of microleakage. In orthodontic practice, our results indicate that the indirect bonding method - with its significant advantages - can be conveniently used. This study was an in vitro study; thus, further clinical studies are needed to strengthen the validity of our results.

- 국문초록 -

직접 부착법과 간접 부착법이 열순환 후 부착강도와 미세누출에 미치는 영향에 대한 연구

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본 연구는 직접 또는 간접 부착법으로 부착한 교정용 브라켓을 열순환 처리 후에 전단 결합 강도(shear bond strength, SBS)와 치아-접착제-브라켓 복합체의 미세 누출을 비교하기 위하여 시행하였다. 50개의 치아우식증이 없는 사람 소구치를 구하여 동등한 2개의 군으로 나누었다. 직접 부착군에서는 광중합 접착제 및 primer (Transbond XT)를 사용하였고 간접 부착군에서는 광중합 접착제와(Transbond XT) 화학중합 primer (Sondhi Rapid Set)를 사용하였다. 중합 후에 치아는 24시간 동안 증류수에 보관하였고 이후 50회 열순환

처리를 하였다. 미세누출의 평가를 위해 각 군에서 10개의 치아에 nail varnish로 추가 봉연을 실시하고 0.5% basic fuchsin에 24시간 동안 염색한 후 입체현미경으로 검경하였다. 만능시험기를 이용하여 각 군의 치아 15개로 SBS를 측정하였고 adhesive remnant index (ARI)를 평가하였다. 결과 자료는 Mann-Whitney U test, Chi-square test, Fisher's exact test로 통계 분석하였다. 직접 부착군과 간접 부착군 사이에 SBS 및 미세누출의 통계적으로 유의한 차이는 보이지 않았으며 간접 부착군에서 통계적으로 유의하게 ARI 점수가 낮았다. 브라켓의 탈락은 법랑질-레진 계면에서 발생하였다. 이상의 결과로 보아 부착법의 차이는 미세누출의 양과 SBS에 유의한 영향을 미치지 않는다.

주요 단어: 간접 부착법, 미세누출, 전단 결합 강도, ARI 점수

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