

A resin veneer for enamel protection during orthodontic treatment

Hideyuki Miwa, Ken Miyazawa, Shigemi Goto, Takamasa Kondo and Akira Hasegawa*

Department of Orthodontics, School of Dentistry, Aichi-Gakuin, University Nagoya and

*GC Dental Products, Aichi, Japan

SUMMARY The aims of this study were to test the tensile bond strength of a recently developed veneer.

Sound premolar teeth (120) extracted for orthodontic purposes were divided into two experimental and two control groups. In one experimental group (V1) 4-META/MMA-TBB resin (4META) was used on the surface veneer prepared with micro particle filled resin (MFR) as an adhesive for bracketing and in the second group (V2) 4META was applied on the surface veneer with the trial resin. For the controls, in group R 4META was used on the enamel surface without veneer and in group G light-cured glass ionomer cement was applied. The 30 samples in each group were divided into three groups of 10 samples and thermal cycled (TC) at 3000, 10,000 or left uncycled. Tensile testing was carried out using an Instron machine. After tensile testing the bond failures in the experimental groups were recorded using a stereomicroscope. Statistical analysis was performed using ANOVA.

In group V2 the resin veneer was able to maintain sufficient bond force to enamel during clinical use. The bond strength of group V1 was significantly higher than that of groups R ($P < 0.05$) and G ($P < 0.01$) at TC 0, but for both TC 3000 and 10,000, the bond strength of group V1 was lower than groups R and G, respectively. There were significant differences between groups V1 and R ($P < 0.01$) for TC 3000, and between groups V1 and R and G ($P < 0.01$) at TC 10,000. The bond strength of group V2 was almost equal to that of group R at TC 0. At TC 3000, group V2 showed significantly lower bond strength than group R ($P < 0.05$), but no significant difference was found compared with group G. At TC 10,000, there were no significant differences between groups V2, R or G. When comparing groups V1 and V2, the bond strength of group V1 was significantly higher than that of group V2 ($P < 0.01$) at TC 0, but the bond strength of group V1 was significantly lower than that of group V2 for both TC 3000 ($P < 0.05$) and TC 10,000 ($P < 0.01$). Comparison between groups R and G, showed that the bond strength of group R was significantly higher than that of group G for both TC 0 ($P < 0.01$) and TC 3000 ($P < 0.01$), but no significant difference was found for TC 10,000. In group V2, nine samples showed adhesive failure between the veneer surface and bracket adhesive before thermal cycling. There were significant differences between the MFR and both trial resin and glass ionomer cement ($P < 0.01$) when examining thermal expansion. No significant difference was found between the trial resin and glass ionomer cement.

It is suggested that application of a resin veneer prior to bracket bonding is suitable for clinical application to protect the teeth and to prevent decalcification and caries.

Introduction

Since the introduction of multi-bracket systems in orthodontic treatment, the most significant progress has been the successful bonding of

brackets to teeth (Bounocore, 1955; Nakagawa, 1969; Mogi, 1982a,b), replacing the former system of cementing preformed bands. However, in order to obtain sufficient bond force to the tooth surface, acid etching is required when resin

adhesive materials are used. The damage caused by acid etching, including dissolution or defects of enamel, has been described (Nakagawa, 1969; Wickwire and Rentz, 1973; Fitzpatrick and Way, 1977; Gwinnett and Gorelick, 1977; Sheykholeslam and Brandt, 1977; Brown and Way, 1978; Matsuda *et al.*, 1979; Younis *et al.*, 1979; van Waes *et al.*, 1997). Furthermore, with commonly used direct bonding systems (Newman, 1965; Miura *et al.*, 1997), several adverse effects have been reported. One of the most frequently encountered problems is localized decalcification of the enamel around the bonded bracket, referred to as a 'white spot' (Gorelick *et al.*, 1982). This may primarily be caused by inadequate patient oral hygiene and poor diet control and additionally, by an increase in susceptibility to caries due to dissolution of the highly calcified prismless enamel by acid etching, or by a reduction of the self-cleaning activity in the area around the bracket base.

Recently glass ionomer cement (polyalkenoate) (Ewoldsen *et al.*, 1995; Silverman *et al.*, 1995; Jobalia *et al.*, 1997; Bishara *et al.*, 1998, 1999; Lippitz *et al.*, 1998) has been used as an adhesive material for the protection of enamel, because no etching is required for its application. However, as it is invariably difficult to maintain an adequate level of oral hygiene throughout the bracketing period, many incidents of caries and decalcification remain.

Based on the concept of enamel protection, coating with a resin veneer (Miwa *et al.*, 1999) has been recognized as a potential pre-treatment for teeth before bracket bonding.

The aims of this investigation were to measure and evaluate the bond strengths of brackets bonded to resin veneers, and to compare the coefficients of thermal expansion of a trial resin, a micro particle filled resin (MFR), and a glass ionomer cement as veneer materials.

Materials and methods

Preparation of teeth

One hundred and twenty sound premolar teeth extracted for orthodontic purposes were collected. The teeth were cleaned to remove all traces of

plaque and other debris, and stored in de-ionized distilled water for 1–6 months. At the start of the experiment, the teeth were randomly divided into four groups (two experimental and two control groups) of 30 samples each. The buccal surfaces of all teeth were free of decay. Their roots were completely embedded in a block of acrylic resin up to the cemento–enamel junction to facilitate placement and retention in the jaws of the testing machine.

Veneer coating method

In the experimental groups, glass ionomer cement diluted to half its standard viscosity and an overlying resin coating were placed on the teeth as shown in Figure 1.

Bracket bonding

Before bonding, the whole of the buccal surface was covered with masking tape in which a hole (3 mm in diameter) was punched to standardize

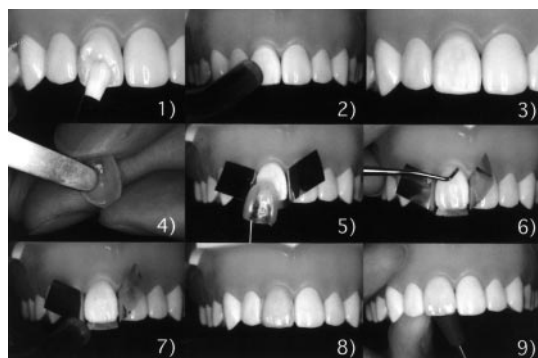


Figure 1 Operative procedure of resin veneer coating (from Miwa *et al.*, 1999). (1) Glass ionomer cement, diluted to half its standard viscosity, was painted in a thin layer using a small brush. (2) Light radiation for 20 seconds to harden the cement. (3) The appearance of the cement layer after hardening. (4) Resin was applied in a thin layer to the inner surface of the transparent matrix which was formed from the labial surface of tooth prior to the procedure. (5) The matrix was placed on the surface and pressed slowly after the bonding agent was applied over the hardened glass ionomer cement layer. (6) Overflowing resin was completely removed. (7) Light radiation for 40 seconds to harden the resin. (8) The matrix was carefully removed as it can be reused. (9) Polishing the incisal edge using silicon points for finishing.

the bonding area in all samples. The materials for the enamel treatment and bracket bonding are listed in Table 1. Figure 2 shows the design of the bracket adhesive method in each group, as follows:

Group V1, experimental group: 4-META/MMA-TBB resin was used on the surface of the veneer prepared with MFR.

Group V2, experimental group: 4-META/MMA-TBB resin was used on the surface of the veneer prepared with the trial resin.

Group R, control group: 4-META/MM-TBB resin was used on the enamel surface without the resin veneer. The enamel was acid etched with 65 per cent phosphoric acid for 30 seconds, washed with tap water and dried.

Group G, control group: light-cured glass ionomer cement was used on the enamel surface treated with 20 per cent polyacrylic acid for 20 seconds, washed and dried.

Thermal cycling

The 30 samples prepared in each group were randomly divided into three groups of 10 samples. Two thermal cycling (TC) conditions were used.

TC 3000 ($n = 10$)

The samples were cycled at 3000 times in a thermal cycling machine (Thomas, Tokyo, Japan) with two temperature-controlled water baths

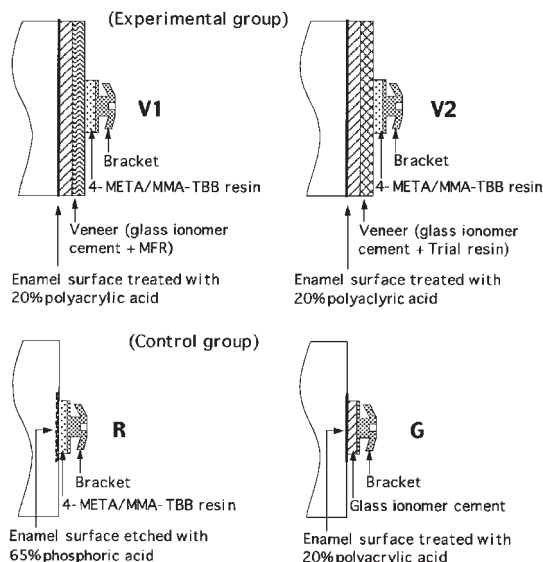


Figure 2 Design of bracket adhesive method in each group.

held at 4 and 60°C. The dwell time in each water bath was 30 seconds.

TC 10,000 ($n = 10$)

The samples were cycled at 10,000 times with the water temperature and dwell time the same as for TC 3000. After thermal cycling was completed, the samples of TC 3000 and TC 10,000 were stored in de-ionized distilled water at room temperature to avoid dehydration until the tensile test was performed.

Table 1 Materials for preparation of sample.

Material	Product name	Manufacturer	Lot no.
MFR	AXIS (T-Clear)	GC	080681
Trial resin	—	GC	—
Glass ionomer cement	Fuji Ortho LC	GC	PWR: 190671 LQD: 220571
20% Polyacrylic acid	Ortho Conditioner	GC	290572
4-META/MMA-TBB resin	Orthomite Super bond	Sun Medical	PWR: 80602 LQD: 80403 CAT: 802042
65% Phosphoric acid	Super Bond etching agent	Sun Medical	70801

GC Corporation: 76-1, Hasunuma-cho, Itabashi-ku, Tokyo, Japan.
Sun Medical: 571-2 Furutaka-cho, Moriyama, Shiga, Japan.

TC 0 ($n = 10$)

The samples were not thermal cycled and were stored in de-ionized distilled water at 37°C for 24 hours starting 1 hour after bracket bonding until tensile testing was performed.

Tensile test

To test the bond strength, each sample was mounted on an Instron machine (Instron, Model 1125, Canton, MA, USA). To stabilize the bracket position and the direction of the tensile force, a double twisted ligature wire (diameter, 0.3 mm; length, 50 mm) and a custom-fabricated stainless steel attachment (length, 30 mm), that could fit snugly around the wings of the bracket, were used in every trial. The tensile force was applied to the bracket base vertically at a crosshead speed of 2 mm/min, as illustrated in Figure 3. Every load-elongation curve was drawn with a pen-recorder. The peak load was recorded as the maximum tensile debonding force and the bond strength was calculated in Megapascals (MPa).

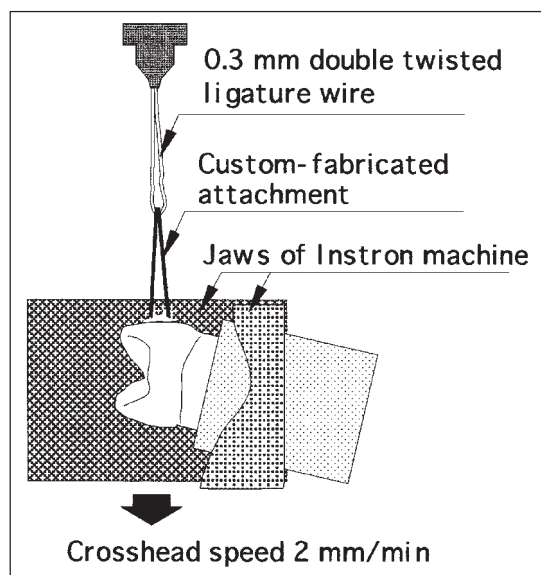


Figure 3 Design of measurement of tensile bond strength.

Statistical analysis

ANOVA was performed between the experimental and control groups to determine whether there were differences in bond strength (Kao *et al.*, 1995).

Bond failure

After tensile testing, the bracket bases and enamel surfaces of all samples in the experimental groups were examined under a light stereomicroscope at $\times 20$ magnification and the bond failure sites were recorded (Kao *et al.*, 1995).

Measurement of the coefficient of thermal expansion

Details of the materials used in this experiment are listed in Table 2.

For preparation of specimens (diameter, 4 mm; height, 8 mm), each experimental material was filled firmly in a columnar hole of a metal mould (DAH-005-12). After pressing both top and bottom with glass plates to fix the form of the specimen, light curing of each side for 60 seconds was performed. All specimens were stored in an incubator at 37°C for 24 hours. After storage, measurements were performed using a thermal analyser (Shimadzu, DT-40, Kyoto, Japan). A holding load of 2 g was applied to the specimen at a rising rate of 2°C per minute with a hold temperature of 100°C. The coefficient of thermal expansion of each material was calculated from the values recorded between 30 and 60°C.

Results

Bracket bond strength

Figure 4 shows the average bond strengths and their standard deviations for all groups. Any score that could not be measured was recorded as 0, because failure of the veneer occurred before the measurement was performed. The results of the ANOVA are also shown.

The bond strength of group V1 was significantly higher than that of groups R ($P < 0.05$) and G ($P < 0.01$) at TC 0, but for both TC 3000 and

Table 2 Material for measurement of coefficient of thermal expansion.

Material	Product name	Manufacturer	Lot no.
MFR	AXIS (E3)	GC	140191
Trial resin	—	GC	—
Glass ionomer cement	Fuji Ortho LC	GC	PWR: 190671 LQD: 220571

GC Corporation: 76-1, Hasunuma-cho, Itabashi-ku, Tokyo, Japan.

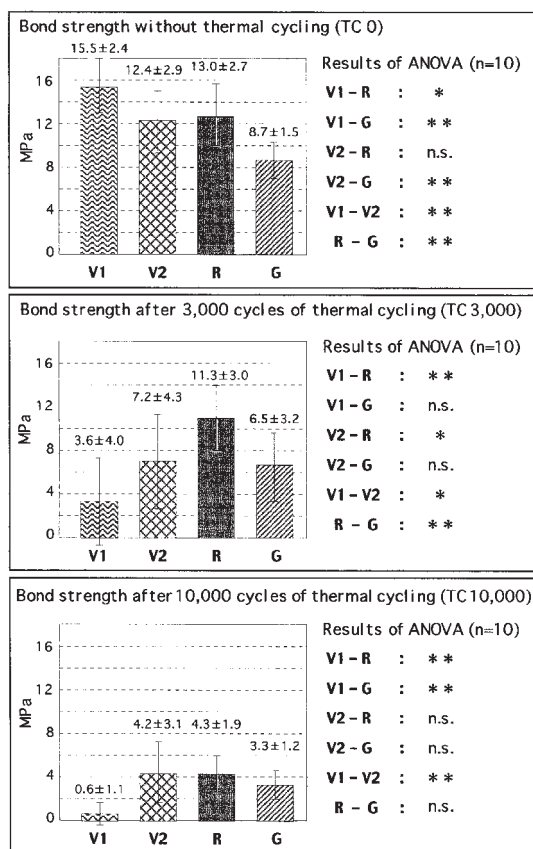


Figure 4 Tensile bond strength at each stage of thermal cycling. n.s., no significant difference, *, $P < 0.05$; **, $P < 0.01$. V1, Bracket was bonded on resin veneer (MFR) using 4-META/MMA-TBB resin. V2, Bracket was bonded on resin veneer (trial resin) using 4-META/MMA-TBB resin. R, Bracket was direct bonded on etched enamel surface using 4-META/MMA-TBB resin. G, Bracket was directly bonded on non-etched enamel surface using glass ionomer cement.

TC 10,000 the bond strength of group V1 was lower than those of groups R and G, respectively. There

were significant differences between groups V1 and R ($P < 0.01$) for TC 3000, and between group V1 and both groups R and G ($P < 0.01$) at TC 10,000.

The bond strength of group V2 was almost equal to that of group R at TC 0. At TC 3000, group V2 showed significantly lower bond strength than group R ($P < 0.05$), but no significant difference was found compared with group G. At TC 10,000, there were no significant differences between group V2 and either Groups R or G.

Comparison between groups V1 and V2 showed that the bond strength of group V1 was significantly higher than that of group V2 ($P < 0.01$) at TC 0, but the bond strength of group V1 was significantly lower than that of group V2 for both TC 3000 ($P < 0.05$) and TC 10,000 ($P < 0.01$).

Comparison between groups R and G showed that the bond strength of group R was significantly higher than that of group G at both TC 0 ($P < 0.01$) and TC 3000 ($P < 0.01$), but no significant difference was found for TC 10,000.

Bond failure

The types of bond failures in the experimental groups are shown in Table 3.

In group V1, veneer fracture was found in nine samples before thermal cycling. After thermal cycling, almost all of the samples showed veneer failure, including those that could not be measured. In group V2, nine samples showed adhesive failure between the veneer surface and bracket adhesive before thermal cycling. After thermal cycling, most samples showed veneer fracture. Only one sample could not be measured.

Table 3 Site and frequency of bond failure.

TC	Site			
	I	II	III	IV
Group V1 (veneer prepared with MFR)				
0	9	—	1	—
3000	2	6	—	2
10,000	—	3	—	7
Group V2 (veneer prepared with trial resin)				
0	1	—	9	—
3000	7	3	—	—
10,000	6	3	—	1

I, Veneer fracture (cohesive fracture).

II, Veneer failure (veneer/enamel adhesive fracture).

III, Bracket adhesive/veneer surface adhesive fracture.

IV, Measurement not determined.

Coefficient of thermal expansion

Figure 5 shows the average coefficients of thermal expansion and their standard deviations for all the experimental materials. The results of the ANOVA are also given. There were significant differences between MFR and both trial resin and the glass ionomer cement ($P < 0.01$). No significant difference was found between the trial resin and the glass ionomer cement.

Discussion

Problems associated with enamel etching

Orthodontic treatment methods have improved considerably since the development of successful bonding of brackets to teeth (Newman, 1965; Miura *et al.*, 1971). Together with the progress

in bonding technology, the system has allowed brackets to adhere to the tooth surface using a minimal bonding area regardless of the bracket material (Zachrisson, 1976, 1978; Lopez, 1980). However, this system is associated with several problems. It is well-known that acid etching induces dissolution of the enamel (Nakagawa, 1969; Wickwire and Rentz, 1973; Fitzpatrick and Way, 1977; Sheykholeslam and Brandt, 1977; Matsuda *et al.*, 1979; Younis *et al.*, 1979) and the debonding process removes the enamel (Fitzpatrick and Way, 1977; Gwinnett and Gorelick, 1977; Brown and Way, 1978; Mochimatsu *et al.*, 1990; van Waes *et al.*, 1997). Nakagawa (1969) reported that the amount of enamel dissolution caused by 65 per cent phosphoric acid etching for 30 seconds was 10–20 μm . Matsuda *et al.* (1979) stated that enamel surfaces damaged by acid etching that had become rough would become smooth again within approximately 3 months due to remineralization or precipitation of amorphous organic matter, but could never be quantitatively recovered. In addition, reduction of the self-cleaning activity and difficulty in brushing in the area around the bracket base may cause 'white spot' lesions (Gorelick *et al.*, 1982) and undermining caries (Kameda, 1974) around the bonded bracket during treatment.

Silverman *et al.* (1972) and Cohl *et al.* (1972) used the system developed by Buonocore (1970,

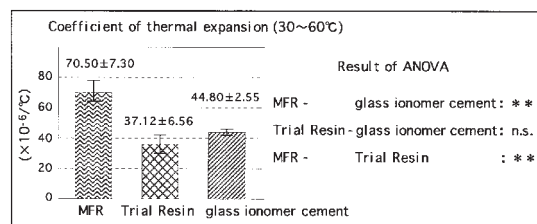


Figure 5 Coefficient of thermal expansion of materials for resin veneer coating. n.s., no significant difference; ** $P < 0.01$. Glass ionomer cement was mixed at powder/liquid weight ratio of 3:2.

1997) (the Nuva-Seal and Nuva-Light system for caries prevention in pits and fissures sealed with an adhesive resin polymerized by ultraviolet light) in orthodontic treatment. A hard film is used to cover the tooth surface entirely before bracket bonding in order to prevent decalcification or caries around the bracket base during treatment. However, acid etching of the enamel is required to obtain sufficient mechanical bond force because the film is a resin, and when the coating film is removed, some amount of enamel has to be removed together with the film that is deeply impacted to the enamel. Unlike procedures employing acid etching, the resin veneer coating technique developed by Miwa *et al.* (1999) using the bonding ability of glass ionomer cement to enamel (Wilson *et al.*, 1983; Higashino, 1987; Akinmade and Nicholson, 1993), never induces damage of the enamel during attachment or detachment of the veneer. It is also well-known that polyacrylic acid (Smith and Cartz, 1973; Farquhar, 1986; Maskeroni *et al.*, 1990) used as a pre-treatment agent produces only a slight etching on clean enamel surfaces, does not make an enamel tag and the adhesive ability of glass ionomer cement to enamel is increased due to formation of a whitish appearance referred to as a 'crystalline deposit' on the enamel surface.

Adhesion of resin veneer

The dwell cycles of the thermal cycling were set at 3000 and 10,000 to correspond to the bracketed treatment period. These cycles would correspond to 9 and 31 months in the oral environment, respectively (Miyazaki *et al.*, 1986). Newman (1965) reported that the maximum force measured on direct bonded brackets was 30 kg/cm² (3.06 MPa) and Miura (1969) stated that the required minimum bond strength for a bracket was 40 kg/cm² (4.08 MPa) in orthodontic treatment. After 10,000 cycles, the bond strengths of samples with a direct bonded bracket using both 4-META/MMA-TBB resin and glass ionomer cement were more than 4 and 3 MPa, respectively, which are sufficient bond strengths for clinical use. On the other hand, the resin

veneer prepared with MFR (Raptis *et al.*, 1979) recorded bond strength values of less than 4 and 1 MPa after thermal cycles of 3000 and 10,000, respectively. This resin is popularly used in prosthetic treatment because a well finished aesthetic restoration may be achieved with a smaller size filler. However, it is known that the mechanical properties of MFR are inferior to those of conventional composite resin, and may cause distortion of the whole resin veneer giving rise to inner stress between the MFR and glass ionomer cement. In this experiment, failure of the veneer prepared with MFR was mainly at the adhesive interface. After 3000 thermal cycles, complete failure of the veneer was revealed in eight samples including two of which could not be measured, and all 10 samples showed complete veneer failure including seven samples that could not be measured after 10,000 cycles. The distortion of the veneer caused by thermal expansion was considered to be a principal factor of failure. In contrast, the trial resin was produced to achieve maintenance of stability of the veneer against many mechanical stresses, especially thermal stress. The results of tensile testing showed complete veneer failure in three and four samples after 3000 and 10,000 thermal cycles, respectively.

To understand in detail the differences between MFR and the trial resin, an experiment was performed to measure the coefficient of thermal expansion of materials for coating the resin veneer. It was found that the coefficient of thermal expansion was similar in the trial resin and the glass ionomer cement, both of which were less than for MFR. The distortion of the trial resin veneer did not occur easily, whilst that of the MFR veneer occurred at an early stage. Even after 10,000 thermal cycles, the veneer prepared with the trial resin remained on the tooth surface and a bond strength of over 4 MPa was recorded at the bracket, which was almost equal to the result of other samples using the direct bonding technique with resin or glass ionomer cement as the adhesive material. The trial resin veneer was less influenced by thermal stress than MFR, and maintained sufficient bond strength for clinical use.

Benefits of veneer coating

The resin veneer is easily applied to the entire tooth surface in this system using a transparent matrix which was prepared for an individual tooth. As all material is polymerized by light radiation, the chair times involved are no longer than for usual bracket bonding procedures. Furthermore, because this veneer consists of a resin as the surface layer and a glass ionomer cement as the base layer, it is sufficiently hard against some mechanical forces, such as brushing and chewing. Additionally, fluoride released from the cement may confer protection against caries, particularly at the cervical margin of the veneers. Therefore, the system is considered to be ideal for the protection of the bracketed tooth surface throughout the entire treatment period.

Conclusions

The principal reason for caries and decalcification may be inadequate oral hygiene and poor dietary control. However, a reduction of the self-cleaning activity in the area around the bracket base may also occur.

The trial resin veneer coated on the entire enamel bracket surface was considered to have sufficient bond strength during the treatment period. It is suggested that treatment of teeth with a resin veneer prior to bracket bonding is suitable for clinical application to protect the teeth and to prevent decalcification and caries.

Address for correspondence

Hideyuki Miwa
Department of Orthodontics
School of Dentistry
Aichi-Gakuin University
2-11 Suemori-dori
Chikusa-ku
Nagoya Aichi 464-0851
Japan

Acknowledgements

We express our sincere thanks to Professor Jiro Hasegawa and Dr Tatsushi Kawai of

Department of Dental Materials Aichi-Gakuin University for their instruction and help in all procedures of this research.

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