Challenges to the clinical placement and evaluation of adhesively-bonded, cervical composite restorations

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Short title: Placement and evaluation of cervical composite restorations

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Abstract

Objectives: The incidence of non-carious cervical lesions (NCCLs) has been increasing. The clinical performance of resin composites in NCCLS was previously unsatisfactory due to their non-retentive forms and margins lying on dentin. In order to address this problem, a lot of effort has been put into developing new dentin adhesives and restorative techniques. This article discusses these challenges and the criteria used for evaluating clinical performance as they relate to clinical studies, especially long-term clinical trials. Polymerization contraction, thermal changes and occlusal forces generate debonding stresses at adhesive interfaces.

Methods: In laboratory studies, we have investigated how these stresses can be relieved by various restorative techniques and how bond strength and durability can be enhanced. Lesion forms, restorative techniques, adhesives (adhesive strategies, bond strengths, bond durability, and the relationship between enamel and dentin bond strengths) were found to have a complex relationship with microleakage. With regard to some restorative techniques, only several short-term clinical studies were available.

Results: Although in laboratory tests marginal sealing improved with a low-viscosity resin liner, an enamel bevel or prior enamel etching with phosphoric acid, clinical studies failed to detect significant effects associated with these techniques. Long-term clinical trials demonstrated that adhesive bonds continuously degraded in various ways, regardless of the adhesion strategy used.

Significance: Early loss of restoration may no longer be the main clinical problem when reliable adhesives are properly used. Marginal discoloration increased over time and may become a more prominent reason for repair or replacement. Reliable and standardized criteria for the clinical evaluation of marginal discoloration should be

established as soon as possible and they should be based on evidence and a policy of minimal intervention.

1. Introduction

Non-carious cervical lesions (NCCLs), which may be caused by erosion, abrasion and/or occlusal stress ('abfraction'), are commonly observed in clinical practice [1]. Restorations for NCCLs are necessary to relieve hypersensitivity, to prevent further tooth structure loss, and to improve esthetics. Unfortunately however, the longevity of resin-based composite restorations for NCCLs was previously unsatisfactory compared to that of anterior approximal restorations [2]. The main reasons for failures were loss of the restoration, secondary caries and/or marginal discoloration [3-5]. This is probably because NCCLs have a non-retentive cavity shape and margins lying on dentin or cementum, which are unfavorable for bonding. In addition, the dentin in NCCLs tends to be sclerotic. Duke et al. [6] have suggested that the more sclerotic that dentin becomes, the more difficult it is to establish adhesion. When we started our laboratory studies, it was speculated that the prevalence of NCCLs would likely increase as a nation's population ages and as the survival times of teeth increase. For the benefit of public oral health, the clinical longevity of restorations for NCCLs requires an urgent improvement. In order to get more insight into this clinical problem, we first performed a series of laboratory studies on clinical placement techniques of cervical resin composite restorations by means of microleakage tests [7-26] and then we have been conducting

clinical trials [27-32].   The aim of this article is to discuss the challenges we faced in the

clinical placement and evaluation of cervical resin composite restorations as they relate to

clinical studies, especially recently published, long-term clinical trials [33-39].

2. Laboratory studies

When considering the mechanisms of gap formation and debonding, two primary approaches appear to be necessary to improve the marginal sealing of cervical lesions. One is the relief of stresses generated by the inevitable polymerization contraction of a resin composite, thermal changes and occlusal forces, and the other is the enhancement of bonding strength and durability.

From 1990 to the year 2000, adhesive technology progressed rapidly and significantly. Most adhesive systems, meanwhile, were frequently replaced by a highly touted successor that lacked clinical validation. In these circumstances, it would be more practical to use laboratory screening tests of a restorative system than to perform clinical trials. If these screening tests were designed to closely simulate optimal clinical conditions, they would be much less expensive than clinical trials and not require several years to elicit meaningful outcomes [40]. In addition, laboratory testing can evaluate the effect of a single variable, if all the other variables are kept constant [40].

Generally the effectiveness of an adhesive system or a restorative technique is evaluated by bond strength tests or microleakage tests. In the past, many studies have failed to clearly demonstrate a close relationship between bond strength and microleakage [41,42]. This may be due to differences in fracture modes between the

bond strength tests and the microleakage tests.   In two-dimensional bond strength tests, most specimens show cohesive failure as bond strength increases.   On the other hand, in three-dimensional microleakage tests, most gaps occur at the adhesive interfaces between cavity walls and restorative materials [13,15].   In this study, we mainly performed microleakage tests since they are more useful in demonstrating the polymerization contraction effect of resin composites as well as the effects of thermocycling and mechanical load cycling.

The basic design of our microleakage tests is briefly described below.   Cavities were prepared at the cemento-enamel junction on the labial surfaces of bovine teeth. These cavities were treated with adhesive systems, following the instructions provided by each adhesive manufacturer.   A hybrid resin composite was then filled in one increment into the cavities and cured for 60 seconds.   After storage in tap water for assigned periods, the specimens were finished, polished, and then divided into a control group and fatigue testing groups.   In the fatigue testing groups, the specimens were subjected to a thermocycle (5-60ºC, dwell time of 15 sec, 5000 cycles) or to a flexural load cycle (approximately 0.5 mm labio-lingual displacement at the incisal edge, 10,000 cycles, 1 Hz), as shown in Fig. 1.   After a 24-hour immersion in 0.5% aqueous solution of basic fuchsin, the teeth were sectioned through the center of the restorations, and the extent of

6

dye penetration, at the incisal enamel (0-3 scale) and at the apical cementum/dentin

margins (0-4 scale), was evaluated. It should be noted that the criteria for microleakage

at the dentin margins changed twice during the 10 year study period. This was done to

discriminate differences between experimental groups since dentin bond strength and

durability increased significantly during this ten year period of time. The data was

analyzed using the Kruskal-Wallis test or the Mann-Whitney U-test (p<0.05).

2.1. Relief of stresses generated by polymerization contraction, thermal changes and mechanical loading

It has been reported that the relief of polymerization contraction stress of resin

composites is related to cavity forms [43], the flow of resin composites [44,45], the

application of flexible intermediate substances [46] and placement techniques [47].

When polymerization contraction of a resin composite exceeds the bond strength to a

cavity wall, a gap at the adhesive interface occurs. Even if a gap does not occur, residual

stress remains at the adhesive interface after polymerization. Greater residual stress

would deteriorate the bond more easily as thermal changes or occlusal forces come into

play. In addition, a small defect at the adhesive interface may become a starting point for

a fatigue fracture. Although there has been no evidence that thermocycling or

mechanical load cycling tests can accurately predict the real life durability of clinical

7

resin composite restorations, these fatigue tests were carried out just to evaluate the bond

durability of the adhesives we tested.

2.1.1. The effect of NCCL forms

Although various NCCL forms are observed [48], only the box form or V-shaped

cavities were prepared in many microleakage vitro studies of cervical resin composite

restorations. Generally, NCCLs in Japan have been restored using adhesive materials

without a cavity preparation (except for the use of an enamel bevel), following the

principle of minimally invasive restorative dentistry established by Fusayama [49].

Therefore, in our studies [7,9], we prepared three cavity designs which simulated typical

NCCLs (viz. wedge-shape (W), V-shape (V) and U-shape (U)) at the cemento-enamel

junction on the labial surfaces of bovine teeth (Fig. 2). These cavities were treated with

Clearfil Liner Bond System, using a 4-step etch-and-rinse adhesive (Kuraray Medical,

Tokyo, Japan). Although Protect Liner, a low-viscosity resin, was recommended by the

manufacturer to be applied in a 4-step process, specimens without Protect Liner were also

prepared to more easily display the effect of polymerization contraction stress.

The microleakage scores are given in Table 1. The incisal enamel margins

showed no microleakage, regardless of the cavity design. The Liner Bond System

adhesive exhibited significantly higher bond strength to enamel than to dentin [50]. The

leakage pattern of this adhesive system may be attributed to its adhesive property. Only the W-cavities showed good marginal sealing in all experimental groups. Feilzer et al. [43] reported that the magnitude of polymerization contraction stress is greatly affected by the configuration of a cavity, and it increased as the C-value (the ratio of bonded surface to unbonded surface) increased. It is assumed that the C-value is related to the ratio of the cavity wall length to the free surface length in the bucco-lingual sectioned surface of a cavity. The values of these ratios for the W-, V- and U-shaped cavities were approximately 1.3, 1.3 and 1.9, respectively. In addition, it was demonstrated that a thinner resin composite layer might have less influence on contraction stress than a thicker layer [51]. Therefore, significantly greater polymerization contraction stress may be generated at the cavity walls of a U-shaped cavity than at the cavity walls on W- and V-shaped cavities.

It is speculated that if a gap occurs in any portion of a cavity, there may be a significant decrease of the induced stress at the other adhesive interface [52]. Therefore, the remaining bond could easily withstand contraction, thermal and mechanical stresses. Therefore, microleakage patterns may change and depend on cavity forms if an adhesive with high dentin bond strength is used. In order to verify this hypothesis, we investigated the microleakage patterns of W- and U-shaped cavities, which were prepared

on the labial surfaces of either the cemento-enamel junction or on the roots of the teeth.

Because Clearfil Liner II displayed similar bond strength to both enamel and dentin, we

used this adhesive for the investigation of microleakage patterns [12].   The microleakage

scores are listed in Table 2.   All of the specimens exhibited a good marginal seal when

they were finished after 24 hours of storage in water.   However, immediate finishing

followed by thermal stress significantly deteriorated the marginal integrity.   No

significant differences in the microleakage patterns were observed between the cervical

cavities and the root cavities, regardless of the cavity design.   These results may be

attributed to the adhesive property of the adhesive system used.   On the other hand, the

microleakage pattern observed in the W-shaped cavities was quite different from that in

the U-shaped cavities.   The incisal portion of a W-shaped cavity has a thicker resin

composite layer than the gingival portion, and greater stress development may result at

the incisal margins [51].   For U-shaped cavities, similar contraction stresses are assumed

to be generated at both the incisal and the gingival margins, since its longitudinal section

has a symmetrical configuration.   As a result, microleakage mainly occurred at the

incisal margins in W-shaped cavities, whereas it occurred at both the incisal and apical

margins in U-shaped cavities.   Our hypothesis turned out to be correct.

Earlier clinical studies suggested that clinical performance of resin composite

restorations in NCCLs was affected by occlusal stress [53,54]. Although several in-vitro

studies of microleakage under loading were attempted, the effects of load cycling on

marginal seals were not clearly demonstrated [55,56]. This is possibly because axial

loads were applied to the specimens in those studies. Flexural loads seem preferable for

cervical restorations, since the etiology of NCCLs is likely related to eccentric occlusal

forces [57]. A lateral displacement of approximately 0.5 mm or 1 mm is much greater

than that encountered in clinical situations. However, this magnitude of displacement

was applied in order to magnify the effect of loading. The W- and U-shaped cavities

were restored at the cemento-enamel junction with 3 types of adhesives and a hybrid resin

composite. This data is listed in Table 3. Flexural loading significantly impaired the

marginal integrity of both cavity designs, even though the microleakage patterns were

different. In the case of U-shaped cavities, only the marginal seal at the apical margins

was impaired by loading, regardless of the adhesive system used. In spite of this, no

bond deterioration was observed at the incisal margins. Generally, in a cantilever, the

moment increases as the distance from the application point increases. Therefore, more

stress may be generated at the apical margins than at the incisal margins, and this was

clearly observed in the exclusive marginal seal deterioration at the apical margins. In the

case of W-shaped cavities, the microleakage patterns depended on the adhesives used.

For Single Bond (a 2-step etch-and-rinse system, 3M ESPE, St. Paul, MN, USA), no bond deterioration was observed. For Photo Bond (an early 2-step etch-and-rinse system without primer, Kuraray Medical), microleakage occurred only at the dentin margins. However, for Liner Bond II-V and Mac-Bond II (2-step self-etch systems), microleakage mainly occurred at the enamel margins. Finite element analysis indicated that more normal stress was induced on the incisal wall than on the apical wall [58]. The properties of individual adhesives may also affect these leakage patterns.

Long-term clinical trials demonstrated that the shape, size and location of NCCLs and the degree of sclerosis did not affect clinical performance [28,34,37-39]. In addition, our clinical trial revealed that the size and depth of NCCLs had no influence on marginal discoloration [32].

2.1.2. The effect of placement techniques

It has been thought that incremental placement techniques reduce contraction stress, and that they lead to an improvement of marginal sealing [47]. Many studies on the effect of incremental placement techniques on marginal sealing and adaptation have been performed [59-64]. However, these results are debatable/dubious because the application techniques [59,60,63], adhesive systems [59-62], resin composites [60] and cavity forms [64] had an influence on the effectiveness of the placement techniques.

Moreover, mathematical analysis of the stresses generated by polymerization suggested that there are problems associated with incremental filling techniques, such as higher tensile stress concentrations at the restoration-enamel interface than those found with single-increment fillings [65].

Our previous studies [7,9] revealed that U-shaped cervical lesions created an intrinsic morphological deficiency on marginal sealing. Therefore, the effect of placement techniques was investigated using U-shaped cavities [10]. The materials and methods used in this study were the same as those in previous studies, with the exception of placement techniques. In the case of the bulk placement technique, the resin composite was cured for 60 seconds, whereas in the case of incremental placement techniques, each increment was cured for 30 seconds (Fig. 3). Microleakage scores are shown in Table 4. When the cavities were restored without Protect Liner, incremental techniques using oblique layers led to a significant improvement in the marginal seal. There was no significant difference between the bulk placement technique and the incremental placement technique with parallel layers. This result supports a similar finding reported by Hansen [63]. The incremental placement techniques that use oblique layers could possibly reduce not only the C-value but also the thickness of a resin composite. As a result, polymerization contraction stress might be decreased by using

these placement techniques. Although placement techniques were found to have no significant effect on marginal sealing when the cavities were restored with Protect Liner, an incremental placement with oblique layers is recommended to restore large and/or deep NCCLs. Regarding the clinical study, no randomized controlled clinical trial (RCT) on the effect of placement techniques was retrieved using a PubMed search.

2.1.3. The effect of a low-viscosity resin lining

Kemp-Scholte & Davidson [46] demonstrated that an intermediate unfilled resin layer between the adhesive resin and the resin composite relieved the polymerization contraction stress of the composite by 20 to 50%. An intermediate layer of a low-viscosity resin composite or a filled adhesive resin may also act as an elastic buffer to relieve the stresses within composite restorations generated by polymerization contraction, thermal changes and occlusal forces [66]. However, Swift et al. [67] reported that the addition of low-viscosity resin composites to adhesive systems, which were not designed for use with such low-viscosity resin composites, did not reduce microleakage.

No consistent results were obtained in our studies with regard to the effect of using a low-viscosity resin liner [7,10,12,23]. This is probably because cavity designs with a low C-factor, placement techniques, high tooth-tissue bond strengths and thick

filled adhesive layers conceal the effect of the application of the low-viscosity resin composite liner.   However, overall findings suggest that the use of a low-viscosity resin composite liner possibly relieves the stresses on the adhesive interfaces generated by polymerization, thermal changes and occlusal forces, and may lead to an improvement in the durability of marginal sealings (Table 1,4,5).

An RCT [68] reported that the use of a flowable resin as a liner under a microhybrid resin composite did not improve the clinical performance of resin composite restorations in NCCLs within a 2-year period.   In that clinical trial, the flowable resin composite was placed only on the bottom of the cavity.   This placement is different from our study because we applied the low-viscosity resin composite to all of the cavity walls as well.

2.1.4. The effect of flowable resin composites

The application of a low-viscosity resin composite liner requires one additional step and, because of this, clinicians are less likely to accept this procedure.   In the late 1990s, flowable composites were introduced to the market as a new type of resin composite.   These restorative materials are created by retaining the same small particle sizes of traditional hybrid resin composites and reducing the filler content by 20 to 25 Wt% [69].   The resulting composite has a lower viscosity and an elastic modulus which

is 33-50% that of hybrid composites [69]. Despite a limited amount of clinical data,

flowable resin composites have been becoming popular because they are easier to handle.

Composites with a lower filler content and/or elastic modulus showed better marginal

sealing in Class V restorations than composites with higher filler content [70].

Therefore, flowable composites would likely demonstrate good marginal sealing and

provide a simplified clinical procedure.

The experimental design and methods used in the study [24] were the same as those

used in a previous study [23], with the exception of the restorative materials used.   When the

restored teeth were not subjected to thermocycling or flexural load cycling, there were no

significant differences observed in the microleakage patterns and scores between the flowable

composites and the hybrid composite (Table 6).   The volumetric polymerization contraction

of resin composites is related to the filler content, and it decreases as the filler content

increases [71].   On the other hand, the elastic modulus of the resin composite mainly

depends on the filler content, and it increases as the filler content increases [72].

Accordingly, flowable composites shrink more and are less rigid than hybrid composites,

and thus the interfacial stress build-up for flowable composites cannot be easily predicted

[73].   The configuration of a cavity is a more important factor in flow related stress

reduction than the type of resin composite used [43,44].   Microleakage scores of the

control group indicate that the polymerization contraction stress may be similar to the bond strength of AQ Bond, regardless of the resin composite used. When the restored teeth were subjected to thermocycling or flexural load cycling, significant differences were observed between the flowable and hybrid composites. Thermocycling deteriorated the marginal integrity of the flowable resin composites, irrespective of the adhesive system used. On the contrary, flexural load cycling did not cause deterioration of the marginal integrity of the flowable composites, resulting in better marginal seals compared to that of the hybrid composite. It should be noted that the adhesive systems used also greatly affect the microleakage patterns that were observed.

In clinical situations, the handling properties of flowable resin composites seem to be very useful for placement procedures involving small or shallow non-carious cervical lesions. However, the overall findings of our study may raise concerns about the marginal sealing of relatively large cervical lesions if they are restored with flowable resin composites. Three RCTs [30,74,75] reported no significant differences in clinical performance between flowable resin composites and microfilled or hybrid resin composites over a 3-year time frame. However, our ongoing RCT [32] revealed that the flowable resin composite had significantly more deterioration between 3 and 6 years than that of the hybrid resin composite. Recently, various types of flowable composites such

as high-, medium-, low- and non-flow have been developed and they are touted as having improved mechanical properties. Further clinical study is required to assess these new products.

2.1.5 The effect of an enamel bevel

Enamel etched with 30-40% phosphoric acid shows sufficient bond strength to prevent gap formation. Our previous studies revealed that the marginal integrity at enamel margins treated with maleic acid or self-etch primer was degraded by thermocycle or flexural load cycling [14,20]. An enamel bevel significantly improved the marginal sealing at enamel margins, as shown in Table 7 [17,22]. The enamel bevel reduces the thickness of the resin composite and changes the cavosurface angle. This may lead to a reduction of stresses generated by polymerization contraction, thermal load cycling and flexural load cycling [17,22,76].

With regard to clinical studies, only two RCTs were available. Both of them showed that the enamel bevel had no effect on clinical performance of resin composite restorations in NCCLs over a 3-year time frame [75,77].

2.1.6. The effect of light curing modes

Flow capacity may also depend on polymerization kinetics [45]. Several studies have revealed that greater shrinkage stress is generated at adhesive interfaces

during the polymerization of light-cured resin composites than that of chemical-cured resin composites [78,79]. This is probably a result of the fact that light-cured resin composites polymerize at a faster rate than chemical-cured resin composites. Although polymerization rate reduction may be achieved by decreasing light intensity [79-82], low light intensity decreases the degree of conversion that is associated with the mechanical properties of the resin composites, and this may result in poor clinical performance of the restorations [83]. Most of the stress reduction is believed to occur during the first 10 s of light activation [78]. Therefore, 'soft-start' polymerization modes, such as the two-step mode and the ramping mode have been developed. These curing modes could significantly reduce shrinkage stress during polymerization [84,85]. However, 'soft-start' polymerization has not displayed any consistent effect on marginal integrity [86-88]. In addition, curing techniques involving very high light intensities, such as plasma arc curing (PAC) and xenon lamp curing, have been introduced to the market [89,90]. The irradiation time recommended by the manufacturers is 3 to 5 s for resin composite restorations. Although it is reasonable to expect a negative effect of such a rapid polymerization process on marginal integrity, this has yet to be confirmed [89].

In our study [25], no significant differences in the microleakage scores were found among the light-curing modes used (standard, two-step, ramping and PAC modes), as

shown in Table 8.   In addition, relatively good marginal integrity was obtained, regardless of the light-curing mode used.   These findings suggest that light-curing modes may have no effect on microleakage in cervical cavities with a small C-factor and a shallow cavity depth when they are restored with a reliable adhesive.   Unfortunately, no RCT investigations are available concerning the effect of light-curing modes.

2.1.7 The effect of finishing and polishing

Immediate finishing and polishing followed by thermocycling significantly deteriorated marginal integrity (Table 1).   It may be possible, over time, to relieve any residual stress resulting from polymerization contraction by relaxation and hygroscopic expansion.   Possibly, residual stress still exists shortly after light activation.   In this circumstance, thermocycling may have more of an effect on marginal integrity. Furthermore, a post-cure interval of 24 hours may enhance mechanical and adhesive properties of resin composites [91].   These findings suggest that it is better to postpone finishing and polishing until the patient's next visit, especially for a NCCL with a high C-value.   No clinical study is available concerning the effect of finishing/polishing time.

2.2. Enhancement of bond strength and durability

If an adhesive had a sufficiently strong bond and it was durable enough to overcome polymerization contraction stress and fatigue stresses caused by thermal changes and occlusal forces, good marginal integrity would be maintained over a long period of time.   The tensile bond strengths of adhesives to bovine enamel and dentin that were determined by our laboratory are given in Table 9.

2.2.1 Enhancement of bond strength to dentin

Until the middle of the 1990s, it was estimated that a 17-24 MPa bond strength was required to prevent a gap formation between restorative materials and dentin cavity walls [92,93].   Bond strengths of adhesives to enamel had already reached this range with the use of phosphoric acid etching, whereas the bonding of earlier adhesive systems to dentin exhibited bond strengths less than 10 MPa.   Therefore, the sustained effort of many researchers has led to the development of adhesive systems which show high bond strengths to dentin.   The evolution of so-called fourth generation adhesive systems has resulted in the production of 2-step self-etch adhesives and 3-step etch-and-rinse adhesives.   Dentin bond strengths are remarkably enhanced by these adhesives and are similar to enamel bond strength [11,13].   Contrary to our expectation, we were unable to demonstrate an improvement of dentin marginal sealing as a result of dentin bond

strength enhancement in the studies, as shown in Tables1-3 and 10 [11,14,18]. In the

case of self-etch adhesives, marginal sealing at enamel margins was degraded by

thermocycling and flexural load cycling, regardless of the cavity form. Polymerization

contraction stress is significantly reduced by gap formation, as described in the section of

the effect of NCCLs forms [52]. In other words, if polymerization contraction stress

exceeds bond strength, this stress increases with bond strength. Therefore, not only the

absolute values of bond strengths but also the relative relationship between enamel and

dentin bond strengths may significantly affect the microleakage patterns of cervical resin

composite restorations. In addition, it is likely that bond durability and stress

distribution affect the microleakage caused by fatigue testing.

After dentin bond strengths reached a sufficient level to prevent early clinical

failures, manufacturers focused on the simplification of clinical procedures. As a result,

2-step etch-and-rinse adhesives and 1-step self-etch, so-called all-in-one, adhesives were

introduced to the market in the late 1990s. A 2-step etch-and-rinse adhesive resulted in

marginal sealing that was comparable to 2-step self-etch adhesives. In our clinical trial

[27,28], there was no significant difference between Liner Bond II (2-step self-etch) and

Single Bond (2-step etch-and-rinse) when it came to 8-year survival rates. As predicted

by the laboratory test [18], marginal discoloration occurred at both enamel and dentin

margins for Liner Bond II, whereas discoloration occurred mainly at the dentin margins

for Single Bond.   However, it should be noted that marginal discoloration was probably

caused by the accumulation of stains at the marginal step or crevice rather than as a result

of microleakage.   On the other hand, earlier 1-step self-etch adhesives showed

significantly poorer marginal sealing, as shown in Table 11 [21,23].   A systematic review

of clinical trials of resin composite restorations in NCCLs revealed the inefficient clinical

performance of earlier 1-step self-etch adhesives [94].   In order to address the problems

of these adhesives, several newer 1-bottle, 1-step self-etch adhesives (with a relatively

thin adhesive layer) were developed in the middle of 2000s.   The newer1-step self-etch

adhesives improved marginal sealing and some products showed equivalent marginal

sealing to that of 2-step self-etch adhesives, as shown in Table 11 [26].   Our clinical trials

[27,31], which were performed using almost the same protocol, indicated that although

there was no difference in 5-year survival rates between adhesives, the incidence and

extent of marginal discoloration associated with the 1-step self-etch adhesives were

greater than that of other 2-step adhesives.   In addition, marginal discoloration of 1-step

self-etch adhesives mainly occurred at enamel margins.   These findings are supported by

another medium-term clinical trial [95].

　　When NCCLs were restored in our clinic, a superficial layer of exposed dentin

surface is removed using a round steel bur at slow speed.   Although saliva contamination prior to priming did not significantly affect dentin bond strengths of the 2-step self-etch adhesive, SEM observations of primed dentin surfaces raised concerns about the durability of bonding to saliva contaminated dentin [96].   Recently, Van Dijken [38] reported that restorations placed in lesions slightly roughened before primer application showed lower loss rates than non-roughened ones.

2.2.2. Enhancement of bond strength to enamel

Enamel etched with 30-40% phosphoric acid shows sufficient bond strength to prevent microleakage.   In most earlier adhesive systems, enamel and dentin were supposed to be treated separately since etching dentin with phosphoric acid might cause hyper sensitivity or pulpal inflammation [49].   However, in the case of fourth generation adhesive systems and 1-step self-etch adhesives, enamel and dentin are simultaneously treated with a milder acid, such as low concentration phosphoric acid, maleic acid, self-etch primers or self-etch adhesives.   Our laboratory studies [11,12,14,18-21,26] indicated that marginal seals at enamel margins treated with these adhesives were degraded by thermocycling or flexural load cycling.   A possible explanation for this leakage pattern is that bond strength and durability to enamel may be decreased by maleic acid treatment or the self-etch systems.

24

2.2.2.1 The effect of an enamel bevel

Marginal sealing at incisal enamel margins was significantly improved by the bevel preparation, as shown in Table 7. This possibly because the enamel bevel decreases tensile stress at the adhesive interface generated by polymerization, thermal changes and flexural loading, as described above. In addition, the bevel increases bonded surface area, and might be able to enhance bond strength. Munechika et al. [97] reported that bond strengths to transverse sections were significantly higher than those to longitudinal sections of enamel prisms. The bevel produces an oblique section of enamel rods, and thus may result in enhancement of bond strength. However, SEM observations have revealed that the bevel preparation alone was not sufficient to prevent a gap formation at the enamel wall, even after 24-hour of storage in water [15]. Only a few clinical trials are available concerning the effect of enamel bevel on the clinical performance of resin composites in NCCLs [75,77]. Although self-etch systems were not used in these studies, they indicated that the enamel bevel had no effect on survival rates after 3 years of clinical service.

2.2.2.2 The effect of the application time of dentin/enamel conditioners

With respect to maleic and oxalic acid, the use of etching times that are longer than recommended by the manufactures showed significantly higher bond strengths [98].

For a self-etch primer, a longer application time also improved the sealing ability at both enamel and dentin margins [99].

2.2.2.3 The effect of prior enamel etching with phosphoric acid

Marginal sealing of 2-step self-etch adhesives and a 3-step etch-and-rinse adhesive with maleic acid was significantly improved by prior enamel etching with phosphoric acid, as shown in Table 12 [16]. An explanation for this is an increase of bond strength to enamel. The degree of surface roughness produced by phosphoric acid is greater than that obtained with the self-etch primer or maleic acid because of its lower pH. This increased surface roughness may possibly provide higher bond strength because the bonding of a resin composite to enamel is mainly based on micromechanical retention [100]. From a clinical point of view, it is almost impossible to prevent an accidental contact of etched enamel with maleic acid or a self-etch primer. Fortunately, the application of the self-etch primer or maleic acid to etched enamel showed no adverse effect on enamel bond strengths or marginal sealing in our study [16]. However, addition etching with phosphoric acid should be limited to enamel since prior dentin etching with phosphoric acid significantly decreased the dentin bond strength [101]. It should be noted that prior enamel etching with phosphoric acid alone could not prevent microleakage when the restorations were subjected to thermocycling. Only prior enamel

etching with phosphoric acid in conjunction with an enamel bevel could eliminate

microleakage (Table 7). Peumans et al. [39] have reported that enamel etching with

phosphoric acid prior to the SE Bond primer had only a few minor effects on marginal

integrity and marginal discoloration at enamel after 8 years of clinical service.

3. Clinical studies

Even if laboratory tests yield favorable results, they do not always result in good clinical performance [41, 102]. Only a well-controlled clinical trial can provide the ultimate proof of clinical effectiveness. Although many clinical trials have been done, most clinical trials have assessed NCCLs over a time frame of less than 3 years. Therefore, we have been performing clinical trials of resin composite restorations in NCCLs over as long a period of time as possible [28,31,32]. Recently, several long-term (7 years or more) clinical trials of NCCLs have been published [33-39]. All of them demonstrated that adhesive bonds continuously degraded with wide variation and that this bond degradation was independent of the adhesion strategy used.

3.1 Clinical problems associated with resin composite restorations in NCCLs

Loss of restoration was the main clinical problem associated with resin composite restorations placed in NCCLs. The magnitude of dentin bond strength that is required to prevent a retention failure is still unclear. However, in our clinical trials, all adhesives used demonstrated excellent retention rates after 5 years, irrespective of the adhesion strategy used. For Liner Bond II and Single Bond, we observed a 100% retention rate, and we observed a 97% retention rate for S3 Bond and G-Bond. This result is supported by other long-term clinical trials [34,39]. Early loss of restoration

may no longer be the main clinical problem when reliable adhesives are properly used.

Marginal discoloration is thought to be one of the first clinical signs that a resin composite restoration is prone to failure [103] and may become a more prominent reason for repair or replacement, especially in general practice, as reported by Browning and Dennison [3]. The incidence of marginal discoloration increased over time, ranging from 28 to 55% at 8 year recalls [28,34,36,39]. In our clinical studies, we used a similar protocol [27,31] and discovered that, after 5 years of clinical service, one-step self-etch adhesives resulted in more marginal discoloration (40-50%) than 2-step self-etch (19%) and 2-step etch-and-rinse (17%) adhesives.

The relationship between marginal discoloration and marginal adaptation has been indicated in many studies [27,39,104]. Indeed, marginal stains were always detected in combination with small marginal defects. However, not all the marginal defects resulted in marginal discoloration [27]. In addition, marginal adaptation seems to be a less common reason to replace cervical resin composite restorations than marginal discoloration [3]. With respect to other categories, such as secondary caries, color match, surface roughness and postoperative sensitivity, clinical problems rarely occurred even in long-term clinical trials [34,36-39]

3.2 Clinical evaluation

The original United States Public Health Service (USPHS) criteria were developed more than 40 years ago and have since become less sensitive for identifying differences between current materials [105]. In order to detect early deterioration, it would be helpful to have a more discriminative scale. Therefore, modified USPHS criteria have been widely used in clinical studies. The USPHS criteria use a grading system based on subjective observations of restorations. It is easy to obtain agreement on retention failure and bulk fracture from evaluator group of evaluators, whereas it is relatively difficult to obtain agreement on secondary caries, marginal discoloration and marginal adaptation. In addition, the transition zone between respective scales makes judgments difficult due to the lack of a clear definition.

Almost all of the marginal stains found in long-term clinical trials were clinically acceptable [28,34,38,39]. SEM observation suggested that marginal discoloration in our studies was caused by the accumulation of stains at marginal steps rather than by microleakage [27]. In addition, most marginal discoloration appeared to be removed by margin repolishing. Long-term observations revealed that the extent or progress of marginal discoloration displayed various patterns within the range of clinically acceptable score [27,28,31,32]. Therefore, for marginal discoloration, the Bravo score was subdivided further, as shown in Fig. 4, in order to aid in the detection of early

differences between the restorative materials in our studies [29-32]. For marginal

adaptation, the criterion was modified to be generous since marginal adaptation is

evaluated more subjectively and it is a less common reason for replacements [28-32].

Meta-analysis provides a highly reliable measure of restoration longevity.

However, meta-analysis of the clinical data of resin composite restorations seems to be

difficult because of the ambiguity of USPHS criteria and the process of conducting and

reporting clinical trials [105,106]. Chadwick et al. [107] comprehensively discussed the

problems associated with outcome measures of restoration failures. There has been a

need for the development of reliable and more objective criteria for clinical performance

of restorations based on evidence and minimal intervention policy. In these

circumstances, FDI criteria were published in 2007 and they should be applied as

standard criteria when restorative materials and/or operative techniques are to be

clinically investigated [105]. These criteria were updated in 2010, modifications and/or

alternatives are possible if good documentation can be presented [108]. In addition, a

web-based training and calibration tool called "e-calib", including several hundred

clinical examples, was made available in July 2008. It will help to spread the

information about the FDI criteria and to facilitate both training and calibration at the

clinical level. Unfortunately, only examples of posterior resin composite restorations are

available at present.　In addition, they appear to need constant improvement.

Replacement criteria may have a great effect on the longevity of resin composite restorations [3,105,106].　Our questionnaire studies on decision-making [109,110] revealed a wide variation in the treatments commonly used for marginal discoloration (Fig. 5 and Table 13).　They also suggested that education, clinical experience and lifelong learning may have some influence on clinically-based decision making. Long-term monitoring of defective restorations has indicated that their progress is usually arrested within several years (Fig. 6).　Therefore, monitoring of marginal discoloration is recommended to aid in proper decision-making.　An open-access guideline like "e-calib" should be prepared for educators, dental students, general practitioners and patients.

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Table 1 The effect of cavity designs on microleakage

Cavity designs	Experimental groups		Dentin margins			
			0	1	2	3
W	LVR (-)	15 min	10			
		15 min + TC	8	2		
		24 h	10			
		24 h + TC	10			
V	LVR (-)	15 min	4	4	2	
		15 min + TC	4	3	3	
		24 h	8	2		
		24 h + TC	8	2		
	LVR (+)	15 min	10			
		15 min + TC	7	3		
U	LVR (-)	15 min		6	1	3
		15 min + TC		1	2	7
		24 h	3	3	1	3
		24 h + TC		1	3	6
	LVR (+)	15 min	9	1		
		15 min + TC	1	7	2	
		24 h	9	1		
		24 h + TC	8	2		

All cavities were restored with Liner Bond System (4-step etch and rinse, Kuraray Medical), whose enamel bond strength was significantly higher than dentin bond strength.

Microleakage did not occur at the incisal enamel margins.

LVR (+): Protect Liner, a low-viscosity resin composite, was applied according to the manufacturer's instructions.

LVR (-): cavities were restored without application of Protect Liner.

TC: specimens were subjected to thermocycle after assigned storage time.

Table 2 The effect of cavity designs on microleakage of resin composites restored with Clearfil Liner Bond II

Cavity designs	Experimental groups		Incisal margins					Apical margins			
			0	1	2	3		0	1	2	3
W	ED	24 h	10					10			
		TC			4	6		9	1		
	DD	24 h	9	1				10			
		TC	4	5	1			10			
U	ED	24 h	9	1				9	1		
		TC	3	5	2				3	7	
	DD	24 h	10					8	2		
		TC	3	2	5			1	2	7	

All cavities were restored with Clearfil Liner Bond II (2-step self-etch, Kuraray Medical), whose dentin bond strength is comparable to enamel bond strength.

W: wedge-shaped cavity, U: U-shaped cavity

ED: cavities were prepared on labial surfaces at cementoenamel junction.

DD: cavities were prepared on labial root surfaces

TC: specimens were subjected to thermocycle after 15 minutes after light irradiation.

Table 3 The effect of cavity designs on microleakge

Adhesives	Cavity designs	Stresses	Enamel margins				Dentin margins			
			0	1	2	3	0	1	2	3
Photo Bond	W	Cont.	10				7	3		
(Kuraray Medical)		LC	10				2	6	2	
	U	Cont.	10					8	2	
		LC	10						2	8
Liner Bond II V	W	Cont.	9	1			8	2		
(Kuraray Medical)		LC	5		5		8	2		
	U	Cont.	6	1	3		8	2		
		LC	3	2	5		3	1	4	2
Mac-Bond II	W	Cont.	9	1			10			
(Tokuyama Dental)		LC	4		3	3	10			
	U	Cont.	7	3			3	4	3	
		LC	7	2	1		1	1	4	4
Single Bond	W	Cont.	9	1			8	2		
(3M ESPE)		LC	10				8	2		
	U	Cont.	9	1			2	7	1	
		LC	10				1		7	2

W: wedge-shaped cavity, U: U-shaped cavity

Cont.: specimens were immersed in the dye solution immediately after 24-hour storage in water.

LC: specimens were subjected to flexural load cycling after 24-hour storage in water.

Table 4 The effect of placement techniques on microleakage (U-shaped cavities)

Placement techniques	Experimental groups		Dentin margins			
			0	1	2	3
Bulk	LVR (−)	24 h	3	3	1	3
	LVR (+)	24 h	9	1		
		TC	1	7	2	
Oblique 2 increments (incisal first)	LVR (−)	24 h	8	1	1	
	LVR (+)	24 h	9	1		
		TC	4	5	1	
Oblique 2 increments (gingival first)	LVR (−)	24 h	7	1	1	1
	LVR (+)	24 h	8	2		
		TC	3	5	2	
Parallel 2 increments	LVR (−)	24 h	1	2	4	3
	LVR (+)	24 h	8	2		
		TC	1	6	3	

All cavities were restored with Liner Bond System (4-step etch and rinse).

LVR (−): cavities were restored without the application of Protect Liner.

LVR (+): Protect Liner was applied according to the manufacturer's instructions.

24 h: specimens were immersed in the dye solution after 24-hour storage in water.

TC: specimens were subjected to thermocycle 15 minutes after light activation.

Table 5 The effect of low-viscosity resin composite lining on the microleakage (W-shaped cavities)

Adhesive systems	Experimental groups	LVR	Enamel margins				Dentin margins			
			0	1	2	3	0	1	2	3
AQ Bond	24 h	−	4	5	1		7	3		
(Sun Medical)		+	9	1			7	3		
	TC	−		2	8		1	7	2	
		+	4	4	2		6	4		
	LC	−	2		7	1	6	4		
		+	5	3	2		6	4		
SE Bond	24 h	−	8	2			8	2		
(Kuraray Medical)		+	8	2			8	2		
	TC	−	3	4	3		8	2		
		+	7	3			8	2		
	LC	−	5	2	3		7	3		
		+	8	2			8	2		
ABF (Protect Bond)	24 h	−	8	2			7	3		
(Kuraray Medical)		+	9	1			8	2		
	TC	−	6	1	3		6	3	1	
		+	9	1			5	2	3	
	LC	−	5	3	2		7	2	1	
		+	8	2			8	2		

24 h: specimens were immersed in the dye solution after 24-hour storage in water

TC: The specimens were subjected to thermocycle after 24-hour storage in water.

LC: specimens were subjected to flexural load cycling prior to immersion in the dye solution.

LVR: lining of a low-viscosity resin composite (Protect Liner F, Kuraray Medical)

Table 6 Effect of resin composite type on microleakage (W-shaped cavities)

Adhesive systems	Filling materials	Experimental groups	Enamel margins				Dentin margins			
			0	1	2	3	0	1	2	3
AQ Bond	Aelite Flo	Cont.	3	5	2		5	1	4	
		TC	1		1	8		2	1	7
		LC	5		3	2	6	2		
	Metafil Flo	Cont.	5	5			4	1	5	
		TC				10		2	5	3
		LC	7	2	1		6	2	2	
	AP-X	Cont.	4	5	1		7	3		
		TC			2	8	1	7	2	
		LC	2		7	1	6	4		
ABF	Aelite Flo	Cont.	8	2			6	4		
		TC	1		7	2	6	2	2	
		LC	8	1	1		7	3		
	Metafil Flo	Cont.	8	2			7	3		
		TC			8	2	1	2	7	
		LC	8	2			7	3		
	AP-X	Cont.	8	2			7	3		
		TC	6	1	3		6	3	1	
		LC	5	3	2		7	2	1	

Aelite Flo (a flowable composite), Metafil Flo (a flowable composite), AP-X (a hybrid composite)

Cont.: The specimens were immersed in the dye solution after 24-hour storage in water.

Table 7 The effect of an enamel bevel on microleakage at the incisal enamel
(W-shaped cavities)

Adhesive systems	Experimental Groups	Bevel	Enamel margins		
			0	1	2
Liner Bond II	Cont.	−	8	2	
	TC *	−			6
	TC *	+	8	1	1
	TC *	PA	10		
Scotchbond Multi-Purpose	Cont.	−	7	3	
	TC *	−	2	1	7
	TC *	+	7	2	1
	TC *	PA	10		
Mac-Bond II	Cont.	−	9	1	
	TC *	−		2	8
	TC *	+	4	6	
	TC *	PA	10		
AQ Bond	Cont.	−	4	5	1
	TC	−		2	8
	LC	−	2		7
	Cont.	+	10		
	TC	+	9	1	
	LC	+	10		
ABF	Cont.	−	8	2	
	TC	−	6	1	3
	LC	−	5	3	2
	Cont.	+	10		
	TC	+	9	1	
	LC	+	10		

Cont.: specimens were immersed in the dye solution after 24-hour storage in

TC*: specimens were subjected to thermocycle 15 minutes after light activati

TC: specimens were subjected to thermocycle 24 hours after light activation

LC: specimens were subjected to flexural load cycling after24-hour storage i

−: without bevel, +: with bevel

Table 8 The effect of light-curing modes on microleakage (W-shaped cavities)

Curing modes	Experimental groups	Enamel margins				Dentin margins			
		0	1	2	3	0	1	2	3
Standard mode	Cont.	8	2			7	3		
	TC	6	1	3		6	3	1	
Two-step mode	Cont.	6	4			5	2	3	
	TC	4	6			4	2	4	
Ramping mode	Cont.	8	2			5	2	3	
	TC	6	4			2	4	4	
PAC mode	Cont.	8	2			7	3		
	TC	4	6			4	2	4	

All cavities were restored with ABF (Clearfil Protect Bond) in conjunction with Clearfil AP-X (a hybrid composite).

PAC: plasma arc curing

Cont.: specimens were immersed in the dye solution after 24-hour storage in water.

TC: specimens were subjected to thermocycle after 24-hour storage in water.

Table 9 Tensile Bond strengths of adhesive systems used in our studies

Adhesives	Manufacturer	Type	Enamel
Photo Bond	Kuraray Medical	conventional total etch	16.6
Liner Bond System	Kuraray Medical	4-step ER	
without Protect Liner			19.1 *
Imperva Bond (DP)	Shofu	3-step ER**	6.5
Imperva Bond (Mix)			26.0
Liner Bond II	Kuraray Medical	2-step SE	17.7
with Protectliner F			19.4
with phosphoric acid			19.8
Scotchbond Multi-Purpose with maleic acid	3M Espe	3-step ER	15.7
Scotchbond Multi-Purpose with phosphoric acid	3M Espe	3-step ER	17.3
All Bond 2	Bisco	3-step ER	18.1
Mac-Bond II	Tokuyama dental	2-step SE	18.3
Single Bond	3M Espe	2-step ER	18.9
Liner Bond II 2V	Kuraray Medical	2-step SE	17.4
SE Bond	Kuraray Medical	2-step SE	20.0
ABF [Protect Bond]	Kuraray Medical	2-step SE	20.6
One-Up Bond F	Tokuyama dental	1-step SE	18.0
AQ Bond	Sun Medical	1-step SE	9.6
iBond	Heraeus Kulzer	1B 1-step SE	10.9
G-Bond	GC	1B 1-step SE	15.5
One-Up Bond F Plus	Tokuyama dental	1B 1-step SE	16.8
S^3 Bond	Kuraray Medical	1B 1-step SE	17.0
AQ Bond Plus	Sun Medical	1B 1-step SE	11.2
Absolute	Dentsply/Sankin	1B 1-step SE	13.6

*: data was quoted from Hosoda et al [50].

**: manufacturer instructs that dentin is treated with Dentin Primer only

DP: enamel and dentin were treated with Dentin Primer.

Mix: enamel and dentin were treated with a mixture of Etching Gel and De

PF: Protectliner F, a low viscosity resin, was applied prior to filling of the

ER: etch-and-rinse system

Table 10 Microleakge scores of 2-step self-etch and 3-step etch-and-rinse adhesives

Adhesives	Cavities	Group	Enamel margins				dentin margins			
			0	1	2	3	0	1	2	3
Liner Bond II	W	Cont.	8	2			10			
		TC			6	4	9	1		
	U	Cont.	9	1			9	1		
		TC	2	4	4		2	1	5	2
Multi-Purpose	W	Cont.	7	3			8	2		
		TC	2	1	7		6	3	1	
	U	Cont.	6	2	2		6	4		
		TC	2	3	5		2	4	4	
All-Bond 2	W	Cont.	10				8	2		
		TC	9	1			6	2	2	
	U	Cont.	10				3	4	3	
		TC	9	1				1	9	

W: wedge-shaped cavity, U: U-shaped cavity

Cont.: specimens were immersed in the dye solution immediately after 24-hour storage in water.

TC: specimens were subjected to thermocycle after 15-minutes storage in water.

Table 11 Microleakage scores of 1 bottle 1-setp self-etch adhesives (W-shaped cavities)

Adhesives	Enamel margins				Dentin margins			
	0	1	2	3	0	1	2	3
iBond	1		7		7	1		
G-Bond	1	2	5		4	4		
One-Up Bond F Plus	4	2	2		2	1	4	1
S^3 Bond	3	4	1		6	2		
AQ Bond Plus		1	7		5	3		
Absolute		1	7		3	5		
One-Up Bond F *				10	6	4		
AQ Bond		2	8		1	7	2	
Mac-Bond II	5		5		8	2		
SE Bond	3	4	3		8	2		

*: specimens were subjected to the thermocycle 15 minutes after light irradiation, except for One-Up Bond F.

One-Up Bond F and AQ Bond are earlier 1-step self-etch adhesives

Mac-Bond II and SE Bond are 2-step self-etch adhesives.

Table 12 The effect of beforehand enamel etching on microleakage (W-shaped cavities)

Adhesive systems	Experimental groups	Enamel margin				Dentin margin			
		0	1	2	3	0	1	2	3
Liner Bond II	Cont.			6	4	9	1		
	PA	7	1	2		9		1	
	PA (−)	7	1	2		8	1	1	
Schotchbond Multi-Purpose	Cont.	2	1	7		6	3	1	
	PA	7	1	2		6	2	2	
	PA (−)	6	1	3		6	3	1	
Single Bond		9	1			6	4		
Photo Bond		10						5	5

All specimens were subjected to thermocycle 15 minutes after light irradiation.

Cont.: cavities were treated with respective adhesive systems according to their instructions.

PA: enamel was etched with 37% acid for 15 seconds prior to the cavity treatment following the instructions.

PA (−): neither LB Primer nor maleic acid were applied to etched enamel walls.

For Single Bond and Photo Bond, enamel and dentin walls are simultaneously etched with phosphoric acid.

Table 13 Questionnaire data for treatments of marginal discoloration (number of respondents*)

Suggested Treatments	Case a	Case b	Case c	Case d
Monitoring	78	75	30	16
Refurbishing	29	8	26	17
Repair	0	12	35	20
Replacement	2	14	18	56

*: total number of respondents was 109.

Captions

Fig. 1 Schematic drawing of the specimen set-up and flexural loading

　　The specimens were set on a testing machine so that the guide plane was located

　　approximately 2.5 mm away from the vertical plane of the plunger.　The table

　　was repeatedly moved in a labio-lingual direction 3 mm against the stationary

　　plunger.　As a result, a lateral (labio-lingual or linguo-labial) displacement of

　　approximately 0.5 mm was applied to the guide plane.　Linguo-labial loading did

　　not affect the marginal sealing [20].

Fig. 2 Lateral and labial views of cavity designs

　　　L: inciso-apical width (mm)

　　　D: cavity depth (mm)

　　　A: cavosurface angle at the apical margin (degree)

　　　C: C-factor

Fig. 3 Various placement techniques

Fig.4 Subdivision of criteria for the Bravo score on marginal discoloration

(a) slight staining; (b) dark-colored localized (less than 1.5mm in length) staining;

(c) dark-colored linear (more than 1.5mm in length) staining

Fig. 5 Decision-making in treatments for various cases of marginal discoloration

Questionnaires including these pictures were sent to 250 randomly selected

alumni of Nagasaki University School of Dentistry.   Although 111 dentists

responded to the questionnaire, 2 dentists did not answer all of the questions.   As

a result, the data obtained from 109 dentists was used for statistical analysis.

Fig. 6 Progress of marginal discoloration

(a) baseline (restored with Single Bond and Clearfil AP-X); (b) at 3-year recall

(marginal discoloration occurred); (c) at 5-year recall; (d) at 14-year recall

Fig. 1

Left diagram labels:
Plunger
Guide Plane
Restoration
Bovine Tooth
Plastic Tube # 2
2 mm
Plastic Tube # 1
Improved Stone
22 mm
30 mm
20 mm

Right diagram labels:
0.5 mm
2.5 mm
Vertical Plane
Guide Plane
3 mm
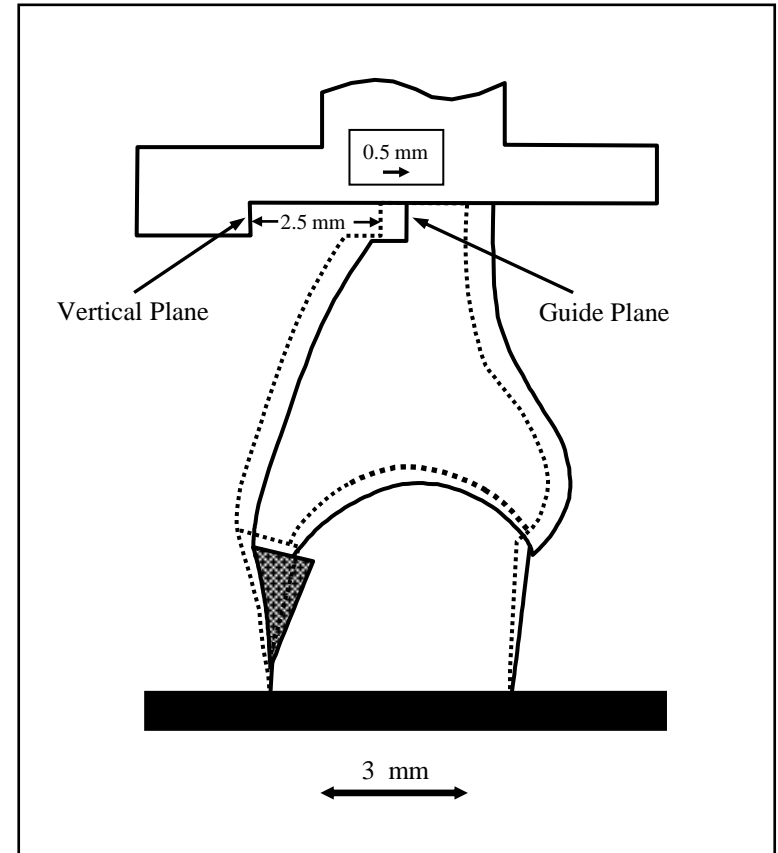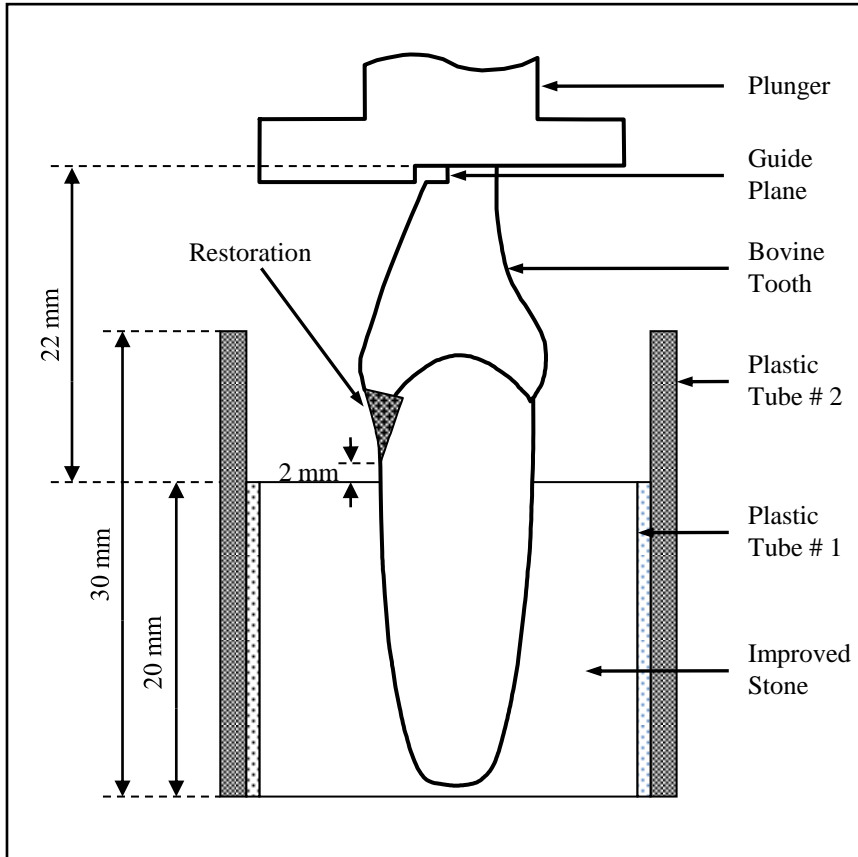
Fig. 2
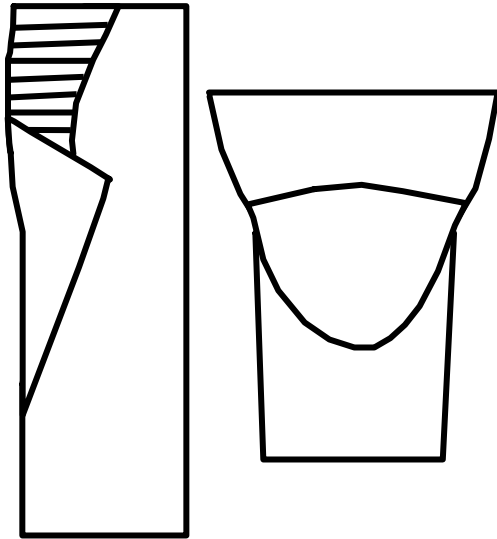
Wedge-shaped cavity

L: 3.0, D: 1.0, A: 165, C:1.3
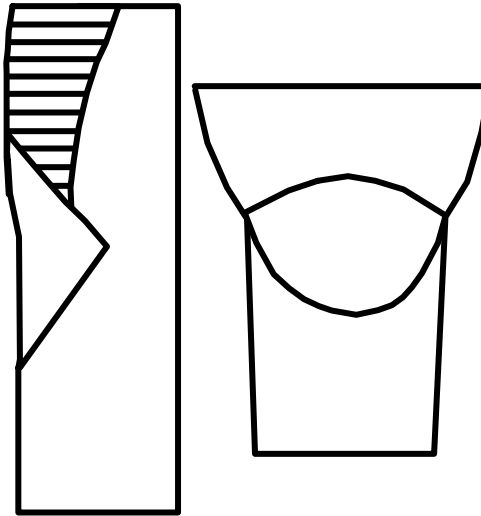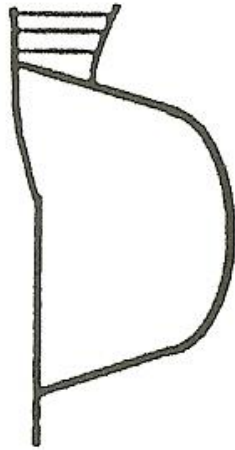
V-shaped cavity

L: 2.6, D: 1.0, A: 140, C:1.3
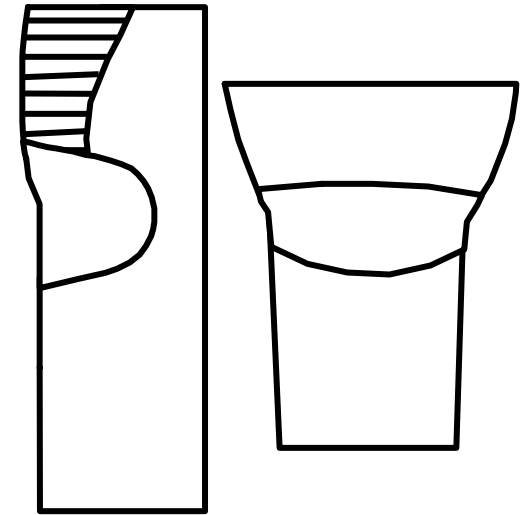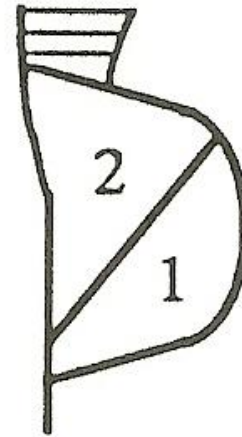
U-shaped cavity

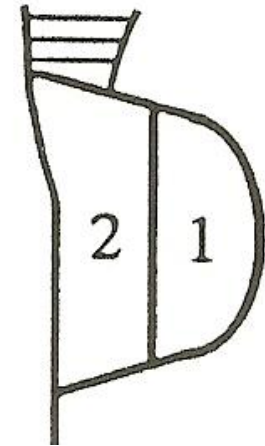**L: 2.2, D: 1.5, A: 105, C:1.9**

Fig. 3

Bulk
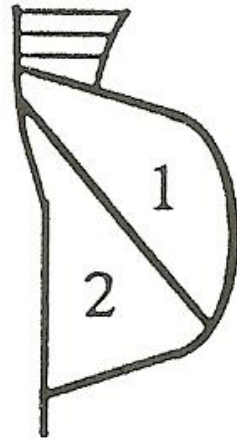
Oblique
2 increments
(insical first)

Oblique
2 increments
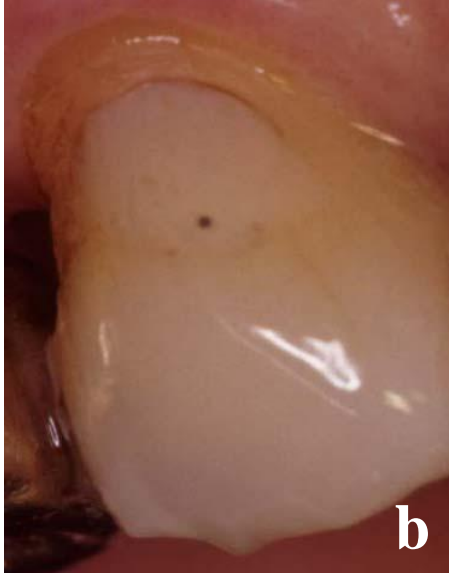(gingival first)

Parallel
2 increments

Fig. 4

Fig. 5

Fig. 6