It is widely believed that postoperative tooth sensitivity after resin composite restoration placement is an unpredictable problem when a total-etching adhesive is used. Restorative procedures that may provide a better seal and reduce postoperative tooth sensitivity have been suggested, e.g. application of a glass-ionomer cement (GIC) lining/base or using a self-etching adhesive (1). However, the benefit of a self-etching adhesive is limited based on reports from clinical studies that the postoperative sensitivity when using a self-etching adhesive is not significantly different from a total-etching adhesive (2-5). Few clinical studies have investigated the benefit of a GIC lining, and the results are controversial (6-8). One study reported that the postoperative sensitivity was reduced when a resin-modified GIC liner was applied over the entire dentin surface before using a two-step, total-etching adhesive (6). In contrast, two other studies concluded that using a protective layer (lining) does not decrease the postoperative sensitivity (7, 8). Moreover, a concern about the sealing ability of a GIC lining on dentine has been raised (9).

For these reasons, the laboratory and clinical studies in this thesis investigated sealing ability and postoperative tooth sensitivity after posterior occlusal resin composite restoration placement with or without a GIC lining. In addition, the effects of a self-etching adhesive on these outcomes were also investigated. The combination of laboratory investigations and a clinical study has two advantages: firstly, a clinical outcome that is consistent with laboratory research data validates the laboratory
experimental approach. Secondly, when the two aspects of the whole research project are in agreement, the laboratory studies can then provide a more biological rationale for the clinical findings.

Based on the experimental data, it was predicted that a GIC liner or the use of a self-etching adhesive rather than a total-etching adhesive would not influence postoperative tooth sensitivity clinically. This prediction was confirmed in the clinical study. In the discussion to follow, the biological rationale for this clinical outcome will be considered, and possible directions for future work will be indentified.

In the experimental studies, three inter-related parameters were investigated: dentine permeability/fluid flow; adhesion (micro-shear bond strength); and gap formation/microleakage (including micro-permeability). The logic in selecting these parameters is that dentinal fluid may move freely into either a micro-gap or through a permeable hybrid/adhesive layer, so that tooth sensitivity may result according to the hydrodynamic theory.

In the fluid flow measurement of cavity-prepared, intact teeth, application of a GIC lining or using a two-step, self-etching adhesive did not reduce fluid flow after restoration when compared with a total-etching adhesive without a lining. It seems that the sealing ability of the total-etching adhesive was comparable with that of the GIC lining and the two-step, self-etching adhesive; this lack of difference in sealing occurred even though dentine permeability significantly increased only after acid etching with phosphoric acid, which may interfere with bonding. The results correspond with another study (10) that showed no significant difference in dentinal seal provided by a two-step, total-etching adhesive or a one-step, self-etching adhesive when positive pulpal pressure was absent (which is similar to the current
work). However, dentinal seal of the total-etching adhesive decreased when the adhesive was exposed to a positive pulpal pressure, while that of the self-etching adhesive did not (10). Other studies also investigated sealing ability (11-14), but dentine permeability/fluid flow was measured through the adhesive layer or bonded dentine without a resin composite restoration, so that the results are difficult to compare.

Dentine permeability after acid etching of caries-affected dentine was markedly lower than that of normal dentine, which is in agreement with the results of two other studies (15, 16), but fluid flow after restoration of carious teeth and cavity-prepared, intact teeth were not significantly different. Thus, a two-step, total-etching adhesive could provide a seal on highly permeable, normal dentine as well as on low-permeable, caries-affected dentine, with or without a GIC lining. Indeed, a GIC lining did not improve the sealing ability of the restoration, regardless of carious teeth or cavity-prepared intact teeth. The result is in conflict with one other study showing that a GIC lining could stop fluid flow after restoration in premolars with an occluso-proximal cavity (17). An explanation might be that the teeth used in that study were less permeable, as their permeability only increased slightly after etching the dentine with phosphoric acid.

In the micro-shear bond test, adhesion to dentine of a two-step, total-etching adhesive was negatively affected by an increase of dentine permeability/outward fluid flow after acid etching when a positive pulpal pressure was present. In contrast, micro-shear bond strengths of a two-step, self-etching adhesive and GIC were not significantly changed by the presence of a positive pulpal pressure. However, it has been reported that bond strength to dentine of GIC may be affected by positive pulpal
pressure, depending on the material (18). The results of the resin-based adhesives are similar to previous reports which compared two adhesive systems (10, 19). Despite adhesion being influenced by dentine permeability, the sealing ability of the total-etching adhesive was not strongly affected and was comparable to the self-etching adhesive or a GIC lining.

The outcomes from internal dye leakage and the micro-permeability test supported the fluid flow results, which showed most of the restorations, regardless of restorative procedures, leaked to methylene blue and the fluorescent dye in a similar manner. One other study also showed that resin-bonded interfaces of total-etching and self-etching adhesives were permeable to a fluorescent dye (20). However, limited fluorescent dye penetration was occasionally observed in the restored carious teeth, but fluid flow after restoration was not different between the two types of restored teeth.

Observation of micro-gap formation showed different results among the restorative procedures. Micro-gaps were initially detected in restorations with GIC lining to a greater extent than in restorations without lining. This finding is supported by the result of another study which reported a higher incidence of micro-gap formation in restorations with a lining (9). In restorations bonded with a self-etching adhesive, micro-gaps were rarely detected up to 1 month, and to a lesser extent than that of a total-etching adhesive.

In restorative dentistry, it is often assumed that laboratory results can be extrapolated to clinical outcomes; otherwise the laboratory studies will have little predictive value. Hence, a clinical trial was conducted to confirm the clinical outcomes that were anticipated from the laboratory results, namely that postoperative
tooth sensitivity would be not significantly different between restorations bonded with or without a GIC lining. This clinical trial was conducted following the CONSORT statement and the recommendations for the clinical studies in dental restorative materials (21, 22) in an attempt to improve the internal and external validity of the study. The investigation was limited to moderate to deep occlusal cavities in young adult patients with the greater risk of postoperative sensitivity (23, 24). Within the limitations of the study, the conclusions can be drawn with a high degree of confidence: a) postoperative sensitivity in daily regular function after occlusal resin composite restoration placement was rare and of low intensity/severity; b) a GIC lining did not reduce the postoperative sensitivity.

The outcome with respect to the resin-based adhesives corresponds with other studies that reported no significant difference in postoperative sensitivity between the two adhesive systems (2-5). Two studies specifically investigated occlusal cavities (2, 5), while the other two studies tested an occluso-proximal cavity (3) or a combination of the two cavity types (4). Most of the studies used the same two-step, self-etching adhesive (Clearfil SE Bond), while the two-step, total-etching adhesives varied. In these studies, short-term postoperative sensitivity to cold stimulation or regular function was reported in 5-20% of patients, usually at a low to moderate level, and no prevalence of tooth sensitivity to occlusal force was observed. A similar trend was found in our clinical trial. It seems that postoperative sensitivity occurs occasionally in association with posterior resin composite restoration placement, but its level is not severe.

The negative outcome of the GIC lining is in contradiction to the other study that showed a benefit of a GIC liner in reducing postoperative sensitivity at 1 week.
(6). In that study, a two-step, total-etching adhesive (acetone-based) was used with or without a resin-modified GIC lining. In contrast, the results of GIC lining are similar to that reported in two other clinical studies (7, 8). However, various dental adhesives and restorative materials were used, and the data were collected from all cavity types in those studies, so comparison of outcomes must be made cautiously.

Postoperative sensitivity is strongly influenced by cavity depth (7). Cavity type and size might also be important factors. Postoperative sensitivity was more frequently detected in occluso-proximal cavities than occlusal cavities (25). Moreover, the larger the size of the cavity, the higher the prevalence of postoperative sensitivity that is anticipated: three-surfaces > two-surfaces > one-surface (25).

The restorations were placed under optimal conditions. The prevalence of postoperative sensitivity in teeth with occlusal and occluso-proximal resin composite restorations placed by final-year undergraduate students was also low (<10%) and comparable to our study (7). Thus, operator skill might not be a significant factor if the restorative procedures are performed carefully. In a randomized clinical trial in which restorations were placed by general practitioners in a faculty clinic, postoperative sensitivity to cold water was low and was not different between posterior teeth restored with resin composite bonded with a two-step, total-etching adhesive and a one-step, self-etching adhesive (26). However, the clinical trial was still in an academic environment even though the restorations were placed by general practitioners.
FURTHER INVESTIGATIONS

Due to the limitation of these studies, further investigations should be conducted as follows:

(1) To investigate the effects of a GIC lining in other cavity types, e.g. an occluso-proximal cavity, which is additionally influenced by the cuspal deflection from occlusal loading (27);

(2) Investigations specific to restoration of deep cavities, which are at greater risk of postoperative sensitivity;

(3) To investigate restorations bonded with the newer one-step (all-in-one), self-etching adhesive, which is more permeable and usually demonstrates poorer adhesion to dentine than the adhesives used in this study (28);

(4) To investigation restorations restored with a low-shrinkage, silorane-based resin composite (29), where less micro-gap formation and fluid flow after restoration are theoretically expected;

(5) A clinical trial set up in a real general practice setting to confirm the external validity of the results.

In conclusion, application of a GIC liner did not improve the sealing ability or reduce the postoperative sensitivity in the posterior resin composite restorations. In addition, using a two-step, self-etching adhesive might not provide a superior seal or less postoperative sensitivity than using a two-step, total-etching adhesive. Further
investigations should be performed to provide more scientific evidence of specific clinical situations on materials where a liner or a self-etching adhesive may supply some benefits.
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