Clinical and laboratory evaluation of immediate dentin sealing
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Chapter 9
General discussion, future perspectives and conclusions
General discussion

This thesis evaluated several aspects of the clinical problem related to adhesion of indirect restorations to dentin. Particularly for minimal invasive restorations that require only partial preparation, longevity is highly determined by durable adhesion of the resin cement to the dentin, as well as the durability of the restorative material itself. Therefore, securing stable adhesion to dentin is essential in that polymerization of the adhesive resin prior to luting ensures a potent hybrid layer. Impairment of adhesion to dentin is possible due to contamination and stress exerted upon the restoration during oral function. Contamination can occur during the fabrication stage of the indirect restoration through saliva, microorganisms in the smear layer, the impression material and the temporary cement. Another aspect of the clinical procedures of extensive restorations is hypersensitivity after tooth preparation. One possibility to tackle these problems is sealing the dentin immediately after tooth preparation (IDS) using one or multiple coats of adhesive resin. Conventional procedures usually seal the dentin before luting the indirect restoration through the so called Delayed Dentin Sealing (DDS) procedure. The systematic review found few studies that focused on the possible merits of IDS but the most convincing were illustrated by the favorable micro-tensile bond strengths when compared to negative or positive controls in vitro. However, no marked clinical benefits of IDS over DDS could be demonstrated on the basis of this review (chapter 2).

In vitro evaluation of IDS and DDS

Application method & Adhesives

Using an adhesive step immediately after exposure of the dentin (IDS) resulted in significantly higher shear bond strength (13.68-17.13 MPa) to dentin compared to DDS (2.46-7.35 MPa), but more more pre-test failures were observed (chapter 3). Similar adhesion parameters of the IDS and DDS applications were further tested using the micro-tensile test. IDS (26.4-40.6 MPa) again performed significantly better than DDS (16-30.2 MPa) (chapter 4). Yet, there was no significant difference between the bond strength results after 1 week and 6 months of aging in water. The specimens failed predominantly at the adhesive-dentin interface in all experimental groups and the incidence of cohesive failures in the adhesive increased after 6 months of aging. Similarly, other in vitro studies reported a higher bond strength of resin-based materials to dentin using IDS (shear: 13.36-19.04 MPa, micro-tensile: 51.1-58.3 MPa) compared to DDS (shear: 0.86-14.9 MPa, microtensile: 1.7-11.58 MPa) although it depended on the test method.6-8

Dentin is typically sealed with adhesive resins with varying pH and chemical properties such as filler content and monomer matrix. Two of the most commonly used adhesive protocols are the etch-and-rinse system and the self-etch system where an etch and prime are combined in one step. Both of these protocols obtained good results in laboratory and clinical studies.9-11 In the in vitro evaluation of IDS and DDS, the shear bond strength results were more in favor of the etch and rinse system (Optibond FL, 7.35-17.13 MPa SD 4.57-6.82 MPa) compared to the self-etch system (Clearfil SE Bond, 3.09-16.05 MPa SD 2.17-4.07 MPa) but the results of the self-etch system showed a smaller standard deviation.
The favourable results obtained by one layer of Optibond FL could be attributed to the fact that this adhesive system is based on the etch-and-rinse protocol where the dentin was initially etched with 37% H₃PO₄. This type of adhesion protocol is considered to be the “gold standard” as the smear layer is removed and the dentin is demineralised. Moreover, this adhesive has high filler content (48 w%) as opposed to the Clearfil SE Bond which is a self-etch adhesive system that does not require a separate etching step and has less filler content (10 w%). The presence of HEMA in both adhesive systems most probably helps to increase the wettability of the adhesive resin but obviously the etching process and the filler content act more effectively on the durable adhesion properties achieved with Optibond FL. These results are also supported by the failure analysis since the adhesive failures between IDS and cement were more commonly observed in the Clearfil SE Bond adhesive system.

Conditioning and cementation

In order to avoid damaging the IDS during conditioning in the luting stage, the adhesive could be applied either in one or more layers or with subsequent application of flowable resin. Based on the results of our shear and micro-tensile study (chapter 3 and 4), such an additional layer with IDS did not (positively or negatively) affect the bond strength results significantly. Even one layer of the self-etch system, and conditioning with silica-coating, had significant benefit compared to the DDS groups. In an attempt to simulate the temporary phase of the indirect workflow, temporary cement was applied on the dentin surface for two weeks in all in vitro studies. After temporary cementation and removal of the provisional restoration, the contaminated IDS layer needed to be cleaned by removing possible impression material and temporary cement and the clean IDS layer could then co-polymerize further with the resin cement. This can be achieved through mechanical cleaning using pumice, prophylaxis pastes or tribochemical silica-coating methods. In our studies the IDS layers were either cleaned with pumice or activated by silica-coating and silanization both of which have contributed to higher bond strength compared to DDS. Conditioning using silica-coating and silane application not only cleans the IDS surface but also roughens and further chemically activates the surface. Particularly considering the incidence of more frequent adhesive failures between the IDS layer and the resin cement after cleaning with pumice, it can be stated that silica-coating and silanization should be involved in the protocol. It is easier to remove cement residues using silica-coating in comparison to a rotary brush and pumice because it is easier to reach difficult parts of the preparation. However, one conditioning method cannot be recommended above the other in terms of higher bond strengths. It has to be emphasized that recognition of the adhesive layer - resin cement junction was microscopically very challenging to assess and requires further research using more sophisticated techniques. Different luting cements were used in these in vitro studies; two were dual-cure resin cements: Variolink Esthetic DC (Ivoclar Vivadent, Schaan, Liechtenstein) and Variolink II (Ivoclar Vivadent) and one was a conventional photo-polymerizing resin composite (HFO, Micerium, Avegno, Italy). The differences between these luting agents were not a subject of investigation in the in vitro studies of this thesis.
Material
Ceramic or composite materials are used in the replacement of missing dental coronal structures. Indirect composite gained interest due to its flexural strength, bio-mimetic properties and less abrasive component to the antagonist.\textsuperscript{13,14} The \textit{in vitro} study of fracture strength, with restorations made of either lithium disilicate pressed ceramic or multiphase resin composite CAD/CAM blocks and bonded to dentin with or without one layer of IDS, evaluated their strength by subjecting them to a chewing simulation of 1,200,000 cycles (chapter 5). The mean fracture strength increased significantly when IDS was employed in the ceramic group but not in the resin composite group. Since ceramic materials are weak under tensile forces, adhesive cementation is fundamental for such materials.\textsuperscript{15} It has to be noted that the IDS layer in this study was further activated using silica-coating and silanization. When the stable adhesion of the IDS to both the dentin and the resin cement-ceramic complex is achieved, under loading conditions, the possible crack formation from the cementation surface could be blocked. On the other hand, resin-resin adhesion is known to be more durable especially after surface conditioning.\textsuperscript{16} This could be the reason for the absence of an additional effect of IDS on the fracture strength of the resin composite material. When fracture results were coupled with the failure types, it was noted that the IDS layer was more frequently stable on dentin after debonding/fracture of both restoration materials which implies that the adhesion to dentin was in fact more stable than the adhesion of resin composite to the intaglio surfaces of the inlays. Moreover, cohesive failure of the inlay material indicates stable adhesion between the enamel/dentin-IDS-cement-inlay complex. Since this type of failure was more common in the tested resin composite, it can be affirmed that durable adhesion and more mechanical strength could be achieved with this inlay material as opposed to ceramic. However, fracture of the inlay coupled with adhesive failure in enamel/dentin indicates less durable adhesion which was observed in the absence of an IDS layer especially for a resin composite inlay material. These observations however, require further affirmation through a larger sample.

In vivo evaluation of IDS and DDS

\textit{Sensitivity}

The IDS technique is reported to lead to improved patient comfort during the provisional phase, with less need for anaesthesia during luting of the restoration, and reduced postoperative sensitivity.\textsuperscript{5,17} However, no sensitivity changes could be detected one-year after clinical service with a minimally invasive preparation design (chapter 6). More postoperative sensitivity is expected with circumferential crown preparations due to more opened dentin tubules at the surface, which are intimately connected to the pulp. On the other hand, self-etching systems have a tendency to minimize post-operative sensitivity, compared to total-etch or milder etching systems due to their higher qualitative and quantitative capacity of penetration.\textsuperscript{18} The implementation of IDS and DDS did not affect the perceived tooth sensitivity in the clinical study after one year. When the risk of postoperative tooth sensitivity is expected to be high, such as in deep preparations or with the use of total-etch systems, the addition of IDS may make a difference in reducing postoperative sensitivity. But clinical factors such as depth of the preparation can never be standardized. Also, the use of polycarboxylate as a temporary cement may have contributed to the lack of difference in sensitivity between IDS and DDS. The polycarboxylate
cement ensures a proper seal of the temporary restoration thereby preventing bacterial invasion in the DDS group.

**Survival**

IDS is also suggested to positively influence bond strengths and gap formations\(^2,3,5-7,17,19-26\) but this has not been investigated in a randomized clinical trial to date. In our within-subject randomized controlled clinical trial, IDS and DDS were compared with respect to survival and success (chapter 7) whereby no significant difference was found after 3 years. This is a short follow-up period to discover a difference between IDS and DDS with respect to survival and success and a difference might be perceivable during a longer observation period. However, some failures, such as chipping and fractures, were only seen in the DDS group and not in the IDS group. Using IDS in indirect bonded restorations facilitates a dentin bond to develop without stress\(^27\) which may have prevented fractures and chipping in the restorations.

Survival and success rates of posterior glass-ceramics were compared in a randomized clinical trial study (RCT, chapter 7) (98.3% and 85% respectively) after 3 years of function and in a prospective study (PS, chapter 8) resulting in a survival rate of 99.6% after 5 years and longer and a success rate of 98.6% and 96% respectively after 5 and 8 years and longer. The results of the PS study are particularly better than those in the literature where survival rates of 92-95% after 5 years and 91% after 10 years were reported.\(^14\) The RCT study was executed by calibrated students in their first, second or third year of their dentistry Master’s program, closely supervised by one dentist. Good oral hygiene was one of the inclusion criteria. Preparation guidelines were very strict; smoothened internal angles and cusps were covered if the remaining tooth wall was less than 2 mm thick from its occlusal aspect or when the outline of the restoration would be in an area with static or dynamic antagonistic contact. All preparations were performed on vital molar teeth. Restorations were luted with a dual-polymerizing luting composite. The PS study was executed by one experienced operator and one experienced dental technician who fabricated all the restorations. There was no active periodontal or pulpal diseases among the inclusion criteria. Preparation guidelines were not that strict, thin walls were not covered, occlusal reduction to allow for restorations to be at least 1.5 mm thick was not followed and occlusal marginal ridge contact was not avoided. Even in devitalised teeth thin walls were not always covered. All procedures were performed using high magnification. Restorations were luted with a conventional photo-polymerizing resin composite. The clinical outcome between the RCT and PS study was different in terms of survival and success rate. The PS study resulted in a higher survival and in an especially higher success rate. Perhaps the fact that the team and the dental school initially had limited experience in providing these types of restorations, and operative procedures were executed by students, may be the reason for this. The difference between operators (for example seating pressure, operating time and experience) on clinical outcome is well recognized.\(^28,29\) An operator with ample experience has more three-dimensional knowledge about preparation design preventing abrupt geometry and thickness variation of the ceramic without following the strict preparation guidelines in general.

Chipping and fractures were only observed in the RCT study in the DDS group; these failures were not
seen in the PS study. In the RCT study, the restorations were followed-up in the mouth and evaluation of the PS study restorations was executed on the basis of photographs and radiographs. Regarding the latter, the condition of the restoration is more difficult to assess. It is advised to make impressions for replicas with SEM recordings to provide additional information on the condition of the restorations. However, it is obvious that no chippings and fractures are seen on using IDS. IDS is thought to improve the adhesion resulting in improvement of the fracture strength in vitro, as investigated in this thesis with the fracture strength study. Polishing the restorations very carefully is executed by the dental technician. If the restorations have the correct height then there is also little need to adjust the ceramic in the mouth. This is easier when the dental technician is more familiar with these kinds of restorations. In the RCT study, the height of the restorations had to be corrected sometimes. If special ceramic polishers are not applied well, it can result in small micro cracks that can lead to catastrophic failures with time.

A dual-polymerizing luting composite was used in the RCT study to lute the glass-ceramic restorations, which is used in the vast majority of studies. Recent studies on the use of a conventional photo-polymerizing resin composite as a luting agent are promising. The higher filler content and lower initiator concentration compared to dual-polymerizing resin cements may be beneficial in terms of mechanical strength and the wear properties at the exposed margins. This technique proved less technique sensitive, because of easier removal of excess cement compared to a low viscous material, and therefore less prone to application errors. Even thick restorations are not contra-indicated with the use of conventional photo-polymerizing resin composite in combination with IDS but the use of a high power photo curing unit (2000W/cm²) and extended polymerization time are considered of critical importance. The use of a conventional photo-polymerizing composite as a luting agent in combination with IDS contributed to a higher survival and success rate in the PS study compared to the RCT study. In general, absolute isolation by rubberdam is of great importance for longevity when using a resin composite.

Future perspectives

In the series of in vitro studies in this thesis, the depth of the cavity preparation and the preparation of dentin were standardized as much as possible. However, the clinical cavity depth is highly dictated by the depth of the caries or tissue loss. Thus, the results of this study, in terms of IDS or DDS bond strength or survival of indirect restorations being better and longer with IDS application, are also influenced by the dentin depth parameter. Adhesion of resin-based materials was reported to be less favorable on deep dentin compared to superficial dentin. Moreover, hypersensitivity as a clinical problem could also be highly affected, not only by the depth of dentin, but also by the preparation parameters such as the speed (rotation per minute-rpm), type of bur, the pressure and duration of drilling. All these parameters should be considered as confounding factors when interpreting results of studies especially related to hypersensitivity. Nevertheless, future studies should perhaps focus more on chemical analysis of the IDS layer and the exposure of dentin after air-abrasion surface conditioning. The survival of indirect restorations should also be reported after long-term clinical service as well as the the failure
types, after clinical function, with a specific focus on the location of the failure in the dentin-IDS-cement-restorations complex analyzed by Scanning Electron Microscopy and fractography.

Concluding remarks and clinical implications
The adhesion and failure type results of the in vitro investigations presented in this thesis (chapter 3 and 4) indicate that at least one layer of IDS is favorable over DDS. Especially lithium disilicate restorations with increased mechanical strength benefit from an IDS application (chapter 5). Furthermore, a contaminated IDS layer should, at the very least, be cleaned using pumice mechanical cleansing methods while surface cleaning and activation of IDS through air-abrasion methods warrants further research (chapter 3 and 4). The in vitro studies identify some differences in outcome resulting from the tested protocols or variables which are generally not reflected in the cruder, clinical outcome measures, such as survival of a restoration. Therefore it was suggested in the systematic review to lute modern glass-ceramics to posterior teeth with adhesive protocols that are the most operator and patient friendly (chapter 2). The results of the clinical studies on the other hand, demonstrated no additional advantages of IDS versus DDS on short-term hypersensitivity, patient satisfaction and clinical survival after 3 years (chapters 6 and 7). Medium-term clinical data on posterior glass-ceramic partial restorations demonstrate that they have an excellent medium-term prognosis when adhesively luted using a photo-polymerizing resin composite in conjunction with IDS (chapter 8).
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