Cementation in adhesive dentistry: the weakest link
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SUMMARY

Cementation in adhesive dentistry
The weakest link
Successfully luting restorations is an important and demanding procedure. The luting cement connects the restorative material to the tooth structure, creating two adhesive interfaces; the tooth-cement interface and the cement-restoration interface. The cement layer is in most cases the weakest link within the restorative system. Failure of the adhesive interface results in debonding, which leads to microleakage and possibly even loss of retention. This thesis mainly handles the topic of restoring endodontically treated teeth. Such teeth are often weakened by loss of tooth material due to disease and invasive restorative treatment. As a result, they often provide insufficient retention for a tooth build-up. Therefore, endodontic posts, e.g. fiber-reinforced composite (FRC) posts, are frequently inserted. To prevent leakage to and re-infection of the peri-apical tooth region, endodontic restorations must meet special requirements. Endodontic posts can be regarded as secondary endodontic root canal fillings and have to fulfill the same requirements. A reliable cementation providing an adequate seal is therefore of paramount importance for clinical success and survival of the restoration. Unfortunately, loss of retention is the most common mode of failure for fiber posts. Other common failure modes for (indirect) restorations concern endodontic failures and secondary caries, which can be attributed to (micro)leakage. Microleakage is the result of a poor bond between tooth structure and the cement layer.

Cementation of indirect restorations is a downright challenge for the clinician. There are numerous factors which are to be considered when luting a restoration. Looking into all these factors was beyond the scope of this thesis. Instead, we focused on the influence of cavity configuration (C-factor), mode of polymerization, and shrinkage stress and strain on the bond between restorative materials e.g. FRC posts, cements and tooth tissue. In addition, the effect of additional pretreatment of a fiber post on bonding to cement was investigated. Finally, the clinical success and survival of resin composite indirect restorations cemented with resin based cement and resin-modified glass-ionomer cement, were evaluated.

Chapter 1, the general introduction of this thesis, provides background information on the etiology of tooth substance loss, and why posts, cores and sometimes even indirect restorations may be required. Special emphasis is given to the contraction stress and shrinkage of resin cements, and the influence of mode of polymerization and C-factor on these phenomena. The most-used cements are described and the difficulties in cementing are explained, both from a scientific and a clinical point of view. The commonly used testing methodologies, including Finite
Element Analysis (FEA), are briefly explained. Finally, the aim and outline of this thesis is described.

In chapter 2, the influence of polymerization mode and C-factor on the cohesive strength of five different dual-cured resin cements was investigated in vitro. The cements were either self- or dual-cured, and placed in cavities consisting of polyethylene or brass tubes with a C-factor of 0 or 25, respectively. The influence of these variables on the cohesive strength was recorded using a microtensile test. It was shown that, depending on the cement, the cohesive strength diminished when the cement was cured in a high C-factor geometry. The cohesive strength of most tested cements was not affected by the curing mode. The clinical relevance of these results is that constraint shrinkage conditions, for example in the case of post cementation in a root canal, can have a negative influence on the physical properties of the cement.

In chapter 3, the influence of surface pretreatment of fiber posts on cement delamination was evaluated using a three-point bending test. Even though the interface between post and dentin is more important from a clinical perspective, it is beneficial to the restoration as a whole to obtain a strong bond at all interfaces. Therefore this study tested different pretreatment methods that might improve the bond between cement and post surface. Three different resin based cements, RelyX Unicem, Panavia F 2.0 and DC Core Automix were tested. The fiber posts were pretreated by means of silanization, sandblasting, a combination of both, and no pretreatment in the control group. The initial and catastrophic failure loads were recorded. Since in all cases delamination of the cement layer occurred at the initial failure load, this was determined to be the delamination strength. The catastrophic failure load corresponded with the fracture of the post. Especially when the conventional, i.e. non self-adhesive, DC Core Automix cement was used, silanization of the fiber posts resulted in higher delamination strengths. It was hypothesized that the functional phosphate groups of the MDP monomers of Panavia F 2.0 as well as the methacrylated phosphoric esters in RelyX Unicem reacted with the fiber post material, diminishing the need for prior silanization of the post, on which the chemical bond with DC-Core Automix depended. However, silanization resulted in delamination strengths closer to the fracture strength of the post for all cements tested.

In chapter 4, a two-step cementation procedure for prefabricated fiber posts was studied. This two-step cementation procedure was designed similar to the layering technique in composite restorations. The aim of this procedure is to reduce the C-
factor in the post space, reducing the polymerization contraction stress and therefore creating a stronger and more reliable bond between post and dentin. The two-step procedure consisted of inserting a Teflon post, slightly larger than the corresponding fiber post, into the post space, and curing the cement. Because of the lack of bonding between the cement and the Teflon, the C-factor of this cement layer was reduced drastically. After removal of the Teflon post, the fiber post was cemented in the space left by the Teflon post, requiring a very thin and uniform cement layer. This procedure was tested with the same cements as described in chapter 3, and the conventional cementation procedure served as a control. The bond strength of the cement was determined with a push-out test. Two-step cementation of the fiber posts resulted in an increase of the push-out strength for all cements tested.

In chapter 5, a finite element analysis was carried out to determine the stresses present when cementing a fiber post using the conventional cementation procedure and the two-step procedure as described in chapter 4. The complete root with a post cemented in it and the push-out specimens as described in chapter 4 were used to create Finite Element (FE) models. In the FE analysis, both the load at failure as determined in the push-out test in chapter 4, and the stresses due to the shrinkage of the cement layer were taken into account, and combined to calculate the total stress present in the models. It was shown that the two-step cementation procedure resulted in a dramatic decrease of stress due to the shrinkage of the cement layer. This decreased stress made the two-step push-out test specimens able to withstand higher loads of failure compared to the one-step push-out test specimens. The latter were already pre-stressed due to the shrinkage of the cement layer. The FE model of the complete root showed that when the conventional cementation procedure was used, the stresses in the cement-dentin interface became very high, so that debonding during functional loading of the cement layer could be expected. This could lead to loosening of the post, or increased microleakage, which is often encountered clinically.

In chapter 6, the shear bond strength to bovine root dentin of three resin-based cements in self- and dual-cure polymerization modes was evaluated. The cements were either applied in bulk, as a thin layer beneath a composite disc, or in a thin layer between two dentin discs. The volumetric shrinkage and polymerization contraction stress in self- and dual-cure polymerization mode of the resin cements was measured. In order to analyze the peak stresses in the shear test at failure, FE models of the different shear bond test set-ups were made. The load at failure determined with a
shear test and the stress due to the shrinkage of the cement layer were used as input in the FE models. Using these values, the maximum shear stresses in the cement-dentin interface were calculated. In shear bond strength testing, dual curing of the cement and applying the cement in thin layers showed higher shear bond strengths compared to self-curing the cements and bulk application. DC Core Automix proved to have the highest shear bond strength values. Volumetric shrinkage developed at a slower rate with the chemically cured specimens compared to the dual-cured specimens. However, after 30 minutes the volumetric shrinkage per cement was comparable, which indicates a similar degree of cure for both curing methods, except for RelyX Unicem, which showed a significantly lower volumetric shrinkage after self-curing. Alternatively, the contraction stress for the chemically cured specimens was significantly lower compared to the dual-cured specimens. Panavia F 2.0 showed significantly lower volumetric shrinkage as well as contraction stress in both curing modes compared to the other cements. Analysis of the shear bond strength test with finite element analysis showed no statistically significant differences between groups, except for RelyX Unicem, which showed higher shear stresses when dual-cured compared to the self-cured specimens. This could be attributed to the lower volumetric shrinkage of RelyX Unicem after self-curing. This was illustrative for a lower degree of cure, resulting in poorer mechanical properties and subsequently a lower bond strength of RelyX Unicem when self-cured. Even though the curing mode had a large effect on contraction stress, the specimens that were cured in a high C-factor geometry, i.e. in a thin layer, did not generate lower shear stresses compared to specimens with the cement cured in bulk. This could be explained by the compliance of the test set-ups. There were no further differences between curing or application methods within the cements. Panavia F 2.0 showed lower shear stress values compared to the other two cements.

In chapter 7, the success and survival of indirect resin composite restorations, mostly full crowns, was evaluated during a three-year prospective clinical study. After three years of clinical service the success rate of the restorations was 84.8% while the survival rate was 91.6%. Cementation with Fuji Plus cement resulted in higher success and survival rates, compared with cementation with 2bond2 cement, although this difference was not significantly different. The same results were observed for restorations on vital teeth compared to restorations on endodontically treated teeth. The relatively high failure rates can possibly be explained by the design of the
preparation in combination with the material properties of the composite material. Preparation designs were similar to those used for metal or ceramic crowns. These materials have much higher e-moduli compared to the tested indirect composite material. This probably had a significant effect on the stress distribution within the restoration, exerting higher stresses on the cement layer and the core. As a result, these parts of the restoration formed the weakest link in the restorative system in the case of the composite restoration.

How to deal with polymerization contraction has been a topic of dental research for a long time. Although its detrimental effect on the interfacial integrity of bonded restorations is well known, the problem has not been solved. This thesis shows that not only the interfacial integrity of the cement-dentin interface may be due to the high contraction stresses, but the integrity of the cement itself may also be affected, resulting in a lower cohesive strength, as described in chapter 2. The problem of polymerization shrinkage can be addressed by applying a two-step bonding procedure, as described in chapter 4. This two-step bonding procedure leads to a lower pretension of the cement layer. As a result, the cement layer is able to withstand higher stresses before failure, as discussed in chapter 5. Apart from the obvious increase in push-out strength, the two-step bonding procedure is very likely to reduce microleakage, and to enhance the cohesive strength and clinical performance of the cement. Further research is needed to test these hypotheses. Optimizing the cementation procedure also requires optimizing the interfacial integrity between resin based cement and restorative material. The results of chapter 3 of this thesis suggest that the usefulness of pretreatment methods for improving the bond strength to fiber posts depends on the type of resin cement. For a conventional resin cement without self-adhesive properties, silanization of the post may be beneficial to optimize the bond between cement and post. Sandblasting does not add retention and can be omitted. An important observation made in chapter 6 is that the degree of cure of a cement significantly influences its bond strength. It is therefore important to select a material that ensures sufficient curing when applied in self-cure mode, because light is not likely to fully reach all parts of the cement layer, for instance in the deeper parts of the post space or beneath an opaque indirect restoration. As is shown in chapter 7, the cement selection may influence the clinical performance of a restoration. Cement selection and cement handling are important factors in achieving a strong and reliable bond between the tooth and the restoration.
The clinician should be aware of the potential problems related to cementation of a fiber post or an indirect restoration. Silanization of the fiber post, especially when a conventional, \textit{i.e.} non self-adhesive resin cement is applied, seems to be an effective way of enhancing the interfacial integrity between resin cement and fiber post material. The weakest link still remains to be the cement-dentin interface, however. Cements should be able to obtain a sufficient degree of cure, even when self-cured, to achieve an adequate bond strength to dentin. Two-step cementation of a fiber post is an efficient and simple procedure that will eliminate most unfavorable polymerization contraction stresses, which will result in a better retention of the post.