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Summary and Conclusions

Thanks to the introduction of bonding techniques in the second half of the last century, restorative dentistry underwent a major improvement. Until then, retention was based on macro-scale undercuts in the preparation of the cavity and sealing of exposed dentine was left in the limited adaptation capability of restorative materials to tooth structure. At the same time, the well-established metal alloy silver-amalgam was gradually replaced by resin-based composites as first choice to restore decayed teeth.

In **chapter 1,** an introduction is presented about technical problems specifically related to modern restorative dentistry. Restoration with adhesive materials offers a paramount advantage over the only close adapting, but not bonding materials because extensive sacrifice of sound tooth structure, for reasons of retention, becomes redundant and perfect sealing can be achieved only theoretically. However, the combination of resin-based materials and bonding ones forms also one of the main pit-falls in today's dentistry. The resins' shrinkage during polymerization and their mismatching modulus withhold a secure wall-to-wall integrity as the arising stresses often exceed the bond strength. Demanding and complicated techniques have been introduced to offer resistance to premature debonding. One of the most successful techniques is to introduce some flexibility in the restoration as a stress absorber. As the restorative material itself has to withstand considerable biting forces and wear, it cannot be too flexible. The usual solution to obtain flexibility within the restored system is to employ a low-module material underneath the strong and hard superficial restorative material. As a matter of fact this is also true for natural teeth where the highly mineralized and wear resistant enamel protects the softer but shock resistant dentine against premature chemical and mechanical erosion. Another way to introduce increased flexibility in the restored system, is to use, at the adhesive interface a thin low modulus bonding layer (lining) at a given thickness rather than an as thin as possible adhesive layer, which is the usual approach in adhesive techniques. It was the purpose of this study to determine on theoretical and experimental basis the optimal values for layer thickness and stiffness to ensure a durable adhesive interface during polymerization shrinkage and mastication. As reliable and strong bonding might also restore some of the lost coherence of the decayed tooth, one of the most critical restorations, a deep MOD in an endodontically treated premolar, was studied.

In **chapter 2**, a computerized model was formulated, in which the great diversity of material's properties and complex geometry of teeth were simulated. By doing so, the analysis of the complicated stress distribution was enabled and the study of the simultaneous interaction of the many variables came into reach. A 3D solid model of a human maxillary premolar was prepared and exported into a 3D finite element model (FEM). Additionally, a generic Class II MOD cavity preparation and restoration were simulated in the FEM by a proper choice of the mesh volumes. A validation procedure of the FEM was executed, based on comparison of theoretical calculations and experimental data. Different rigidities were assigned to the adhesive system and restorative materials. Two different stress conditions were simulated: (a) stresses arising from the polymerization shrinkage and (b) stresses resulting from shrinkage stress in combination with vertical occlusal loading. Three different cases were analysed: a sound tooth, a tooth with a Class II MOD cavity, adhesively restored with a high elastic modulus composite (25 GPa) and another with a lower one (12.5 GPa). The cusp movements induced by polymerization stress and (over)-functional occlusal loading were evaluated. The higher the rigidity of the restoration material was, the higher the cusp displacement, due to the pre-stressing from polymerization shrinkage and the lower the cusp movements when stressed by occlusal loading.

This preliminary study by 3D FEA on adhesively restored teeth with a Class II MOD cavity indicated that Young's modulus values of the restorative materials play an essential role in the success of the restoration. Premature failure due to stresses arising from polymerization shrinkage and occlusal loading can be prevented by proper selection and combination of materials.

In **chapter 3**, attention was given to the role of the thickness and the module of the bonding layer in adhesively restored teeth. Once again restored teeth were modelled by 3D finite element analysis, this time with lining data included. Subsequently stress distribution, and redistribution of the stress for different lining designs were investigated to determine premature failure during polymerization shrinkage and occlusal loading. Simulation of Class II MOD composite restorations with a resin bonding system revealed a complex biomechanical behaviour arising from simultaneous occurring processes like polymerization shrinkage, composite's stiffening, occlusal loading and system's deformation. For a given polymerization contraction, the stress increased proportionally with the rigidity of the composites used in the restoration, whilst the cusp movements under occlusal loading were inversely proportional to the rigidity of the composites. The adhesive layer's deformability plays thus a relevant role in the attenuation of the polymerization and occlusal loading stresses. An appropriate adhesive layer, capable to (partially) absorb the composite deformation, can keep the stress within acceptable limits. For adhesives and composites of different rigidities, finite element analysis (FEA) allows the determination of the proper adhesive layer thickness leading to optimal stress release in order to preserve the interface integrity.

In **chapter 4**, cusp fracture resistance of adhesively restored, endodontically treated premolars has been investigated for various material combinations. Class II MOD preparations and endodontic treatment were carried out on extracted sound maxillary premolars. Cavities were restored with an amalgam in combination with two different bonding systems, three different resin-based composites with their respective bonding systems, one of these composites in combination with a conventional glass-ionomer or two different resin-modified glass-ionomers and a composite in combination with a compomer. Fracture resistance was measured by axial loading in a testing machine. Resin-based composites, in combination with dentine bonding systems in bevelled MOD preparations, rendered the tooth a cusp fracture resistance, which did not differ significantly from that of sound teeth. Bonded amalgam and a sandwich of glass ionomer cement/resin composite in bevelled preparations were significantly weaker in resisting cusp fracture than sound teeth, but still significantly stronger than the unrestored tooth with a MOD preparation. It was statistically apparent that several adhesive restorative systems could satisfactorily be used to restore teeth after endodontic therapy. From this study, it may be concluded that hybrid resin composites in combination with hybridizing bonding systems are the materials of first choice to restore endodontically treated teeth if full coverage by cast metals is not indicated.

In **chapter 5**, adhesively restored deep Class II MOD restorations were submitted to simulated functional (dynamic) loading (fatiguing) in order to assess debonding at the margins of cervical dentine. MOD preparations and endodontic treatment were carried out on extracted sound human maxillary premolars. The cavities were restored with seven different material combinations: three different resin-based composites, two bonded amalgam combinations and two sandwich combinations, a resin-based composite with a poly-acid modified resin-based composite (compomer) or another resin-based composite with a resin-modified glass-ionomer. For each group, half of the samples were exposed to mechanical loading and the other half served as control. Imperfect bond formation and debonding due to loading were determined by dye penetration. In addition, the dye penetration scores were correlated with the cusp fracture strengths of similarly prepared restorations used for the study described in chapter 4. After functional loading, the resin-based composites, in combination with hybridizing dentine bonding agents, showed better preservation of marginal integrity than the sandwich restorations, which in turn performed better than the amalgam restorations. It was demonstrated that debonding correlates with reduction in fracture resistance. Under the conditions of this study, it can be concluded that debonding of adhesive MOD restorations due to functional loading can be prevented best by using resin-based composites in combination with hybridizing dentine-bonding systems. Success can be increased by a bonding layer consisting of a lightly filled resin, which appears in substantial thickness. With elapse of time, debonding due to functional loading should be anticipated.

It took a long time since the first publications (Kemp-Scholte and Davidson, 1990a and b) on the positive stress reduction effect of application of thin interfacial low modulus layers in resin-based composite restorations that this relative easy procedure got wide acceptance in restorative dentistry. Fortunately, the manufacturers nowadays deliver their bonding agents, which essentially only should be low-viscous resins capable to infiltrate the acid-etched substrate to a certain depth, as lightly filled resins. By doing so, formation of a substantial thick layer on top of the resin-impregnated substrate is guaranteed. This might be one of the major reasons of greater confidence amongst opinion leaders in the success and perfect seal of resin-based composite restorations (Fischer, 2002; Kanka, 2002; Suh, 2002; Van Meerbeek, 2002).

From this *in vitro* and computer study, it can be concluded that it is still difficult to restore endodontically treated teeth free of any leakage with adhesive techniques and plastic materials. The marginal integrity of the restorations in hybrid resin-based composites in combination with hybridizing resin bonding systems showed to be resistant to functional loading. Imperfections of the bond, due to polymerization shrinkage stress or mechanical functional loading, will not only negatively affect the sealing of the restoration, but might also affect the resistance to fracture.