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Summary

Tooth-colored materials such as resin composites should be safely used for patients in terms of clinical behavior. Esthetics are more or less a side aspect in the posterior region. However, it is probably the most important issue for patients all over the world to receive invisible restorations. This summary section picks up relevant issues having been addressed in the introduction section **(Chapter 1)** to build a thematic bridge in this thesis and to provide some framework for future thoughts.

Resin composite materials are well-suited materials to bond to tooth hard tissues and furthermore to support enamel and dentin in terms of cuspal adhesive stabilization. It is well-proven that adhesion in dentistry can be safely applied in many ways, such as pit and fissure sealings, direct and indirect resin composites, and bonded ceramic restorations. Bonding to phosphoric acid etched enamel is accepted to be clinically successful, however, marginal staining or gap formation have been also reported as major incidents already after medium-term observations. Also dentin can be bonded and sealed successfully, being rather quickly represented by the absence of postoperative hypersensitivities. When no hypersensitivities occur, the dentin seal should be estimated to be sufficient, at least to avoid fluid movement inside the dentin tubules. Long-term bonding degradation over time is interesting to observe, therefore it was the topic of the second part of the thesis to do so **(Chapter 2)**. Also, the central idea was to accelerate degradation in vitro, in this case degeneration of resin-dentin bonds by artificial saliva compared to mineral oil (control). Resin-dentin beams bonded with three different etch-and-rinse adhesives (two-step: Prime&Bond NT, Excite/three-step: All-Bond 2) were prepared after 3 years of storage in the described media and subjected to transmission electron microscopy (TEM). An "extreme control" was introduced by autoclaving at 121°C and 103kPa. The TEM images clearly showed that the extreme control scenario did not result in denatured collagen when having been protected by adhesive resin. The control group with mineral oil exhibited almost intact hybrid layers over 3 years with minimal silver deposits, whereas in the test group with artificial saliva, extensive nanoleakage was observed. All ultrastructural parameters, i.e. extent of nanoleakage, interfacial staining characteristics, and the structure of the collagen fibrils in hybrid layers and underlying dentin were completely different and revealed considerable aging processes when storage was accelerated using artificial saliva.

Dentin bonding is more responsible for proper dentin seal and consequent reduction of postoperative hypersensitivities. In contrast, enamel bonding is important for restoration retention and marginal integrity, i.e. unstained margins, especially in the visible area. Therefore, in the next stage marginal quality in enamel and dentin was evaluated simultaneously in vitro and in vivo. This was achieved by starting both investigations at the same time to get comparable results between preclinical and clinical investigations **(Chapter 3)**. In this section, 32 in vitro specimens were compared to 22 in vivo specimens regarding marginal adaptation in enamel and dentin. Clinically, replicas of baseline investigations and 6-year recalls were compared, and in vitro we investigated replicas initially and after 2190 days of water storage with and without thermomechanical loading for accelerated aging processes under a SEM. Due to inferior proximal access to dentin margins, marginal adaptation to dentin was only assessed in vitro. Here, percentages of gap-free margins dropped from 98-100% at the beginning to 55-66% after thermomechanical loading alone and 67-75% after water storage alone and to 42-52% after both accelerated aging mechanisms together. Enamel margins remained 100% gap-free in vitro and 86-90% in vivo at the beginning, dropping to 85-87% after water storage and thermomechanical loading in vitro and 74-80% in vivo. So besides some more artifacts and overhangs due to the more challenging clinical situation, results in marginal quality were almost identical between in vitro and in vivo specimens.

After having worked out the value of accelerated aging on resin-dentin and resin-enamel bonding behavior, the following step was to focus on material properties of resin composites for posterior use. Especially flexural strength and flexural fatigue behavior have been of special interest for us due to the fact that it received increased attention facing increasing marginal and bulk fracture rates in clinical trials dealing with direct resin composites. A thorough evaluation of flexural fatigue characteristics was therefore the aim of the next chapter of the present thesis **(Chapter 4)**. Following the same strategy as in Chapter 3, here we also simultaneously started both in vitro and in vivo evaluations. For the in vitro part, elastic modulus, flexural strength, and flexural fatigue limit according to the staircase method were assessed. In vivo, clinical fracture behavior in terms of marginal breakdown and bulk fractures/chippings were observed and correlated to the outcome detected in vitro. In vitro results showed similar values initially, however, flexural fatigue limits were higher for Grandio compared to Tetric Ceram. In contrast, no such differences occured in vivo up to the

6-year recall of the same materials having been under investigation. Only at a closer view, facing x200 magnification of marginal breakdown sites, revealed that Tetric Ceram showed more areas of marginal defects (7.9%) compared to Grandio (4.8%).

The ultimate instrument for definitive estimation and judgement of dental biomaterials is still the randomized clinical long-term trial. A prospective clinical long-term trial was carried out over a 6-year observation time, using the same restorative materials (Solobond M/Grandio, Syntac/Tetric Ceram) previously described **(Chapter 5)**. Thirty patients received at least two different restorations in a random decision according to recommendations of the CONSORT statement. Thirty-six Grandio restorations were bonded with Solobond M, 32 Tetric Ceram restorations were bonded with Syntac (only Class II, 52 MO/OD, 16 MOD or more surfaces). Twenty-four cavities (35%) revealed no enamel at cervical margin, 33 cavities (49%) exhibited less than 0.5 mm cervical enamel width. At the baseline initial recall, after 6 months, 1, 2, 4, and 6 years, all restorations were assessed according to modified United States Public Health Service (USPHS) criteria by two independent investigators using loups with x3.5 magnification, mirrors, probes, bitewing radiographs, impressions, and intraoral photographs. The overall success rate was 100% after 6 years of clinical service, while drop out of patients was 0%. Neither restorative materials nor localization of the restorations had a significant influence on any criterion after 6 years. However, molar restorations performed worse than premolar restorations regarding marginal integrity (4 years), restoration integrity (6, 12, 24, 48 months), and tooth integrity (4 and 6 years). Irrespective of the resin composite used, significant changes over time were found for all criteria applied in clinical examinations. Marginal integrity started with a major portion of overhangs in all marginal areas having been detected until the 1-year recall and distinctly dropping afterwards (overhangs at baseline 44%; 6 months: 65%; 1 year: 47%; 2 years: 6%; 4 years: 4%; and 6 years: 3%). Beyond the 1-year recall, more and more negative step formations due to wear were found. Tooth integrity significantly deteriorated due to increasing enamel cracks over time. Enamel chippings or cracks were significantly more frequently observed in molars than in premolars. Main reasons for decreasing "restoration integrity" were visible signs of surface roughness and distinct wear traces. Visible wear of both materials under investigation was earlier detectable in molars (74% bravo after 4 years) than in premolars (40% bravo after 4 years).

The final question remains and is addressed with the last issue of the present thesis, i.e. what is this all about or in different words: Is clinical performance of bonded restoratives predictable in the lab **(Chapter 6)**? It could be repeatedly shown that the easiest way of predicting clinical behavior is assessment of marginal integrity. Here the best correlation between in vitro and in vivo results can be found. The explanation is clear: restoring real teeth with real restorations and loading them with real forces being similar to subcritical loads in vivo finally results in realistic estimations of later observable clinical behavior. It was clearly shown that by use of etch-and-rinse adhesives a tight enamel seal is provided both in vitro and in vivo being well-suited to counteract polymerization forces and to withstand occlusal stresses in the oral cavity. However, this estimation is not correlated to the risk for secondary caries, because gap formation not always, nor quickly results in the formation of secondary caries. Here a complex biofilm acts on different tooth hard tissues, which is extremely hard to simulate under in vitro conditions using an artificial mouth. So the final correlation gap-caries is clearly not yet achieved with present investigations having been carried out for the present thesis. Regarding fatigue behavior related to flexural strength, the literature reveals that promising initial flexural strengths do not logically mean high FFLs and an FFL of >30 MPa may be the critical threshold value for bulk fatigue in order to withstand masticatory forces and clinical fatigue over its lifetime. This furthermore supports the aspect that thorough in vitro screening of dental biomaterials is only sufficient when long-term fatigue phenomena are considered in order to get accelerated aging. Regarding clinical wear, few 3D laser scan studies are available in the literature, reporting wear rates after 3 years of clinical service of ~80 µm. Altogether, there is a certain value for accelerated in vitro testing of dental biomaterials which is very highly esteemed because financial resources get smaller, and ethics committees' approval are harder to obtain.

In conclusion, the present thesis clearly shows that in vitro research will be even more important during the next decade of research in restorative dentistry.