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CHAPTER 7

Summary and conclusions

The general introduction in **Chapter 1** gives background information on the various available solutions for replacement of a single tooth. A rationale for the use of resin-bonded fixed dental prostheses (RB-FDPs) and especially two-unit cantilever RB-FDPs is provided. Subsequently, the use of FRC for the manufacturing of fixed dental prostheses (FDPs) is described, while framework design and clinical performance of fibre-reinforced composite fixed dental prostheses (FRC-FDPs) is discussed in detail. The second part of the general introduction focuses on the material science behind fibre-reinforced composites. First of all resin-based composites in general and fibre-reinforced composites in particular are introduced. The classification of resin-based composites depending on their general composition is explained. Subsequently, the composition of dental fibre-reinforced composites is discussed in detail. Thermosetting polymers, such as dimethacrylates and epoxies, are identified as the most widely used matrix polymers, while the most popular fibre reinforcement is glass fibre. The manufacturing of dental fibre-reinforced composite (FRC) is described. Furthermore, the principles of fibre reinforcement, the flexure- and fatigue properties of FRC are discussed. The aim of this thesis is to provide a better understanding of the influence of fibre-reinforcement on mechanical properties and prosthesis designs.

The first part of the thesis focuses on the mechanical properties of particulate filler composites (PFC) and FRC and bridges the gap towards their potential use in cantilever resin-bonded fixed dental prostheses (RB-FDPs).

Previous studies reported a beneficial effect of fibre-reinforcement on the fracture strength and fatigue resistance of dental resin-based composites, but never took the multi-vectorial nature of the forces occurring during physiological function into account. In **chapter 2** the influence of fibre-reinforcement on the fracture strength and fatigue resistance of resin-based composites was investigated. The fracture strength was obtained by means of a cantilever beam test, while the fatigue resistance was obtained using a rotational cantilever beam fatigue testing device. The rotational fatigue testing method exerts a multi-vectorial stress on the specimens to be tested in a sequence of tension and compression each cycle. In fact, the direction of the applied stress represents the clinical situation where stresses on occlusal surfaces vary from parallel to the surface to perpendicular. The used test methodology subjects each point of the circumference of a specimen repeatedly to tensile stress. It was concluded that fibre reinforcement has a beneficial effect on fracture strength, fatigue resistance, work-of-fracture, and failure mechanism of resin-based composites. The high fatigue

resistance and their favourable failure mechanism make FRCs useful in stress bearing situations.

The first step in closing the gap between material properties and clinical behaviour is to design an *in vitro* test which provides information on how the material responds to clinical circumstances. Beams made of PFC and FRC luted to bovine enamel simulated two-unit cantilever RB-FDPs in **chapter 3**. This test set-up made it possible to investigate the influence of fibre-reinforcement and luting cement on the static and dynamic failure load of simulated two-unit cantilever RB-FDPs. The static failure load was determined with a peel test, which was identified by earlier research as most clinical relevant test. The dynamic failure load was once again determined with a rotating cantilever beam fatigue test. This study pointed out that fibre reinforcement has a significant effect on static and dynamic failure load of simulated two-unit cantilever RB-FDPs, which was not influenced by the type of luting cement. This study revealed also a difference in failure behaviour between PFC beams and FRC beams. PFC beams fractured, leaving the bonded part on the tooth surface, while FRC beams partially debonded from the tooth surface, leaving fibres connected to the enamel surface. It should be taken into consideration that the fibre reinforcement fulfils a fail-safe situation, because even after connector fracture the fibre reinforcement protects the FDP from complete debonding. Coincidentally, uncured FRC turned out to be prone to aging after their packaging was opened several months previously. A significant drop in dynamic failure load was observed for aged FRCs. It was concluded that FRC seems suitable for the fabrication of two-unit cantilever RB-FDPs, but the question how FRC performs in comparison to other materials, such as metals and all-ceramics remains.

The second series of studies focussed on prosthesis design. Initially, the use of FRC for designing anterior as well as posterior cantilever RB-FDPs was evaluated. Both studies can be seen as the second step in bridging the gap towards clinical reality.

Three dimensional finite element analysis was used to study the mechanical behaviour of anterior two-unit RB-FDPs made of different framework materials in **chapter 4**. The model consisted of a two-unit cantilever RB-FDP replacing a maxillary lateral incisor with a wing-shaped retainer on the central incisor. Five different framework materials such as, direct fibre-reinforced composite, laboratory fibre-reinforced composite, metal, glass-ceramic, and zirconia were compared. It was concluded that RBFDP made of FRC provided a more evenly distributed stress pattern from the loading area towards the abutment tooth than the other framework materials. Maximum principal stress was identified at the occlusal embrasure of the connector for

all framework materials, which highlights the importance of proper connector design. Advanced stress analyses suggested a difference in predominant failure mode; connector fracture for FRC-, and glass ceramic-based RB-FDPs and debonding for metal-, and zirconia-based RB-FDPs. A stress concentration was found at the contact area between the pontic and the adjacent tooth, indicating that a part of the applied load is transferred towards the adjacent tooth. Such favourable stress transfer should be recognised by clinicians and researchers as an important design factor potentially influencing longevity of FRC-FDPs.

During the course of the previous study the question rose if cantilever FRC-FDP would be eligible for use in the posterior area of the oral cavity. Therefore, in **chapter 5** the influence of retainer design on the strength of two-unit cantilever glass fibre-reinforced RB-FDPs was investigated. Two inlay retained designs and two wing retainer designs were evaluated for replacing a missing premolar with a dummy attached to a first molar. The finite element analysis approach was used to reveal the stress distribution in order to be able to explain the observed failure modes. The wing-retained RB-FDPs showed significant higher fracture strengths than the inlay-retained RB-FDPs. A dual wing with 180 degrees wrap around was due to its favourable failure mode identified as the ideal retainer design for replacement of a single premolar with a two-unit cantilever glass fibre-reinforced RB-FDP.

Chipping and delamination of the veneering composite, due to inadequate design of the FRC framework, is identified as one of the most frequently occurring failures with FRC-FDPs under clinical conditions. Therefore, in **chapter 6** the influence of framework design on the load-bearing capacity of laboratory-made three-unit inlay-retained FRC-FDPs for loading in the occlusal fossa and at the buccal cusp was evaluated. A new anatomical framework design made of unidirectional FRC and short glass-fibre containing fibre-reinforced composite (S-FRC) was proposed and compared towards a non-reinforced design, two conventional designs and three modified framework designs. First of all, this study revealed that the load-bearing capacity of FRC-FDPs was affected by the loading condition. Clinicians should be aware of the fact that FRC-FDPs are more prone to failure during eccentric movements, which highlights the need of cusp protected or a well-balanced occlusion in combination with FRC-FDPs. It was concluded that S-FRC improves the load-bearing capacity of FRC-FDPs and that modified framework designs suffered less delamination than conventional designs. Therefore, delamination and chipping of the veneering composite can be reduced by using an anatomical framework design made of unidirectional FRC and S-FRC.

The series of studies conducted in this thesis showed that FRC is superior in comparison to PFC with regard to strength and fatigue properties. Furthermore, these investigations proved the potential of FRC to be used in an indication that can be regarded as the worst case scenario, namely two-unit cantilever RB-FDPs. Even posterior cantilever RB-FDPs seem within reach. In conclusion it was shown that a recently introduced S-FRC is a viable material for designing a new anatomical framework. The introduction of new indications and new prosthesis designs into daily clinical practice can not be based on laboratory studies only. Therefore, future research should focus on the evaluation of these new developments during properly designed randomized clinical trials.