Medizinische Hochschule Hannover
Klinik für Zahnärztliche Prothetik und Biomedizinische Werkstoffkunde

Dissertation Proposal

Fatigue Analysis via the Finite Element Method for Ceramic Fixed Dental Prostheses Considering the Influence of Peri-Implantitis

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Time frame: May 2021 - April 2024

1. Advisor
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1 Motivation

Fixed Dental Prostheses (FDP) are used for the replacement of lost teeth. They exist in different configurations (crowns, implant, bridges, etc.) and materials (mainly titanium and ceramics) [1]. Their use has been increasing in the general population, but specially among the elderly [8].

A typical ceramic used for such applications is zirconium dioxide (also known as zirconia), specially in its *Yttrium-Stabilized Zirconia* (Y-TZP) form [1, 11].

Due to the typical functional load expected for its application (mainly non-uniform varying load due, among others, to mastication), fatigue is one of the main concerns for the long term reliability of FDP [10].

Another issue regarding the reliability of dental implants is the bone loss due to peri-implantitis, as it can lead to a reduced structural support of the implant [1].

Therefore, it is of interest to investigate the interaction between these two mechanisms of failure for FDP, as both effects (fatigue and peri-implantitis) are of the long-term cumulative damage type. It is expected that a progressing peri-implantitis will reduce the support rigidity of a dental implant (either as a single implant or as support for a bridge), leading to higher stresses for the same functional loads, which in turn can lead to a premature fatigue failure.

The main hypothesis for the proposed dissertation is that there is a quantifiable interaction mechanism between these two effects (damage due to fatigue and peri-implantitis). This would allow to answer when and under which circumstances the mechanical failure of the FDP will occur.

This topic is considered a proper fit to the research group of Prof. Dr. Stiesch, as an extensive range of work performed under her orientation, both in experimental [3, 5] as also in simulation-based [2, 4, 7] studies, already cover the structural strength of FDP (both dental implants as also bridges) under different conditions.

2 Goal of Thesis

The objective of the proposed dissertation is to elaborate a fatigue model for ceramic FDP. This model shall consider not only the long-term effect of the functional loads (e.g. mastication), but also the adverse effect on the support of the implant due to bone loss caused by peri-implantitis.

The *Finite Element* (FE) structural model will be verified via simplified analytic calculations and validated via *in-vitro* experiments. Finally, *Stress-Number of Cycles* (SN) curves will be obtained experimentally for Y-TZP and used to validate the created fatigue model. These curves will be obtained both for the conditions with and without the influence of peri-implantitis. This influence will be represented via a reduced base support of the dental implant.

3 Approach

At first, a simplified analytic model of the bone-FDP system will be developed. This model will be used as a base case for calculation of fatigue damage using SN fatigue curves from the literature and for verification of a FE model for a simplified geometry of the bone-FDP system. The FE model will be created using the structural module of the software *Ansys Workbench 2020*.

Once the initial FE model is verified, successively more complex and realistic models will be created considering different factors of influence, as for example: preload [4], type of support [6], type of force application [7], etc. This initial model will at this stage consider only single static loads.

Ideally, at this point of the project, mechanical tests will be performed to validate experimentally the FE model. Alternatively, already existing tests (e.g. see [3, 5, 9]) can be reproduced via simulation with the created model to expedite the work and avoid the repetition of tests already performed within the research group. The objective of these tests are not only to validate the FE model, but also to obtain the parameters for SN fatigue curves for the ceramic material (Y-TZP) used.

With a verified and validated FE model, the next step is its further development to include structural fatigue effects. This will be realized via an automation script to be written with the programming language *Python* [12]. It will, based on a input list of load-cycles, automatically drive the simulation of all load cases and calculate the cumulative damage on pre-defined points based on the calibrated S-N curves.

As a further development of the FE model, a damage routine for the jaw bone will be implemented (also in *Python*), to include the effect of bone loss due to peri-implantitis. This damage routine will progressively reduce the base support of the implant via elimination of mesh elements representing the bone around the base of the implant (i.e., reduction of the rotational rigidity). Also this FE model shall be validate via experiments. These experiments can be similar to the ones performed previously, with the main difference being in the reduction of the base support during the long-term cyclic loading.

4 Project Plan

Sketch of a time line for the dissertation with major activities and milestones:

Time	Activities	Milestone
Jul - Dec 2021	a) Simplified analytic model for base geometry b) FE Model verified with a) c) FE Model for realistic/complex geometry d) Use of SN curves from literature for fatigue analysis using c)	– Paper on conference about simplified fatigue model for FDP
Jan - Dec 2022	e) Simplified experimental model to validate a) and b) (obtain rotation rigidity of supports) f) Experimental model (including cyclical loading) of realistic/complex geometry to validate c) and d)	– Article on journal about experimentally validated FE-based fatigue model for FDP
Jan - Dec 2023	g) FE Model for geometry with progressively reduced base-support due to peri-implantitis h) Experimental model (including cyclical loading) of realistic/complex geometry with progressively reduced base-support to validate g)	– Article on journal about experimentally validated FE-based fatigue model for FDP considering the effect of peri-implantitis
Jan - Apr 2024	i) Compilation of results and dissertation writing	– Dissertation defense

Table 1: Planned Time Table

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