ACCURACY OF CAD- AND CT-BASED FE MODELLING TO PREDICT THE FATIGUE BEHAVIOR OF POROUS TITANIUM DENTAL IMPLANTS

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Introduction

Due to their improved osseointegration potential, 3D-printed porous dental implants are gaining growing interest [1]. While providing sufficient porosity for functionalization, such implants must exhibit appropriate fatigue strength to comply with the relevant standards. Finite element (FE) modeling has the potential to simulate time-consuming fatigue testing and thus shorten the design process [2]. The present work aimed at developing and calibrating a tool to predict fatigue behavior of porous implants by combining monotonic testing and FE simulation (Fig. 1) and compare accuracy of CAD-, or CT-based FE modeling.

Methods

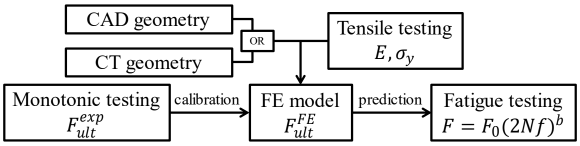

Figure 1: FE-based workflow for fatigue life prediction.

Simplified test samples of 4.5 mm-diameter cylinders mimicking dental implants were designed based on the requirements of the ISO 14801. A fully porous section of 4.5 mm height was introduced around bone level (Fig. 2a). Two different unit cell geometries (Schwarz Primitive (SP) and Schwarz W (SW)) and three porosity levels (50%, 60% and 70%) were combined to generate six designs: 50SP, 60SP, 70SP, 50SW, 60SW and 70SW. 144 samples (24 per design) were manufactured by selective laser melting in Ti6Al4V (EOSINT M270). µCT imaging was performed to assess effective geometries of four samples per design (vivaCT, Scanco). Uniaxial tensile testing was performed on 3D-printed dog bone shaped samples to determine elastic modulus E and yield stress (σ_y). The porous samples were tested in vitro under bending compression at 30° off-axis load according to ISO 14801. Four samples per design were tested monotonically to determine ultimate load (F_{ult}^{exp}) (Instron 5866). Fatigue testing was performed at five load levels: 50%, 35%, 25%, 20%, and 15% of F_{ult}^{exp} (DYNA5dent, DYNA-MESS) with four samples at each level to measure the number of cycles to failure (Nf). Fatigue data was fitted with $F = F_0(2Nf)^b$, assuming a constant b, to determine F_0, the specific fatigue force, for each design.

Linear elastic FE models (Fig. 2a) were built using two techniques, CAD-based and CT-based. The estimated monotonic failure F_{ult}^{FE} was defined as the load level for which the von Mises stress $\sigma_{VM} > \sigma_y$ in a constant volume fraction %V of the porous region. %V was determined via best fit between F_{ult}^{FE} with F_{ult}^{exp} (Fig. 1). In a second step, fatigue life prediction was performed via linear regression of F_{ult}^{FE} and F_0 (Fig. 1). With α and β being the regression coefficients, the FE prediction of the fatigue resistance can be expressed as:

$F = (\alpha \cdot F_{ult}^{FE} + \beta)(2Nf)^b$

Results

Fatigue behavior was accurately predicted for all designs except for the 60SP one that was overestimated by 34.1% (Fig. 2b). CT-based FE achieved stronger correlation between experimental and predicted specific fatigue force (R^2=0.87) and lower average prediction error (10.0%) than CAD-based FE (R^2=0.73 and 18.3%).

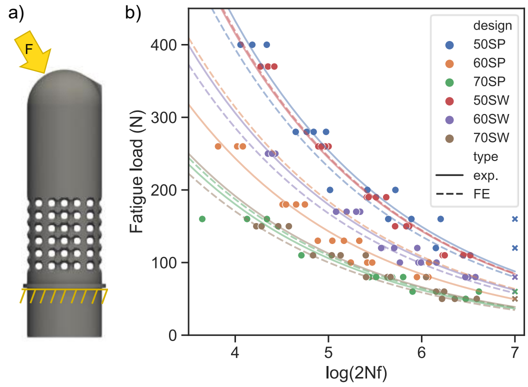

Figure 2: a) Sample design 60SP with loading conditions indicated in yellow; b) fatigue load – life plot (cross = survival), experimental data regression (full line) and CT-based FE prediction (broken line).

Discussion

The developed FE-based approach can accurately predict implant design's infinite fatigue life. This tool, requiring only simple monotonic testing for FE model calibration, can be an efficient surrogate for time consuming fatigue testing and therefore accelerate the development process of porous implants. By accounting for the differences between planned and printed geometries, CT-based models were more accurate than CAD-based models.

References

1. Wally et al, Metals, 5(4):1902-1920,2015.
2. Wang et al, Proc Inst Mech Eng H, 233(2):170-180, 2019.

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