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Influence of dental restorations and mastication loadings on dentine fatigue behaviour: Image-based modelling approach

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ABSTRACT

Objectives: The aim of this study was to use Finite Element Analysis (FEA) to estimate the influence of various mastication loads and different tooth treatments (composite restoration and endodontic treatment) on dentine fatigue. The analysis of fatigue behaviour of human dentine in intact and composite restored teeth with root-canal-treatment using FEA and fatigue theory was performed.

Methods: Dentine fatigue behaviour was analysed in three virtual models: intact, composite-restored and endodontically-treated tooth. Volumetric change during the polymerization of composite was modelled by thermal expansion in a heat transfer analysis. Low and high shrinkage stresses were obtained by varying the linear shrinkage of composite. Mastication forces were applied occlusally with the load of 100, 150 and 200 N. Assuming one million cycles, Fatigue Failure Index (FFI) was determined using Goodman's criterion while residual fatigue lifetime assessment was performed using Paris-power law.

Results: The analysis of the Goodman diagram gave both maximal allowed crack size and maximal number of cycles for the given stress ratio. The size of cracks was measured on virtual models. For the given conditions, fatigue-failure is not likely to happen neither in the intact tooth nor in treated teeth with low shrinkage stress. In the cases of high shrinkage stress, crack length was much larger than the maximal allowed crack and failure occurred with 150 and 200 N loads. The maximal allowed crack size was slightly lower in the tooth with root canal treatment which induced somewhat higher FFI than in the case of tooth with only composite restoration.

Conclusions: Main factors that lead to dentine fatigue are levels of occlusal load and polymerization stress. However, root canal treatment has small influence on dentine fatigue.

Clinical significance: The methodology proposed in this study provides a new insight into the fatigue behaviour of teeth after dental treatments. Furthermore, it estimates maximal allowed crack size and maximal number of cycles for a specific case.

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1. Introduction

As the third most common cause of tooth loss after dental caries and periodontal disease, tooth fracture has a profound influence on dental health care.[1,2] According to the clinical reports, root canal treatment is specified as a major cause of tooth fracture.[3,4] Furthermore, cavity preparation, followed by tooth restoration also influences the tooth strength. Since dental treatments lead to tissue loss, it is considered that changes in the geometry and replacement of tooth tissues with artificial materials are one of the major factors inducing increased risk of failure.[4–6] From the biomechanical aspect, the failure may occur due to a single load that exceeds the strength of the tissue or due to the fatigue caused by a cyclic loading.[7,8] The focus of this study was on the fatigue caused by habitual loading – mastication, where the intensity of a single load is much lower than the intensity of the critical breaking force.[9] Cyclic mastication load causes cyclic stress changes which, over time, may cause degradation of mechanical properties, initiation and growing of micro-cracks and, consequently, tooth fracture – "fatigue failure". Tooth fracture is often related to dentine failure, since this tissue occupies the majority of the tooth.

Most of the studies focusing on dentine fatigue were based on in vitro experiments performed on standard test specimens cut from the bulk of dentine.[10–14] These studies contributed to better understanding of dentine as a material, but they did not analyse dentine as a part of a complex tooth structure. Moreover, the influence of dentine structure deterioration and mechanical properties caused by fatigue still remains unclear. It is difficult to perform multiple physical tests on a single specimen. In addition, precise measuring of physical quantities (such as stress, strain, displacements, temperature, etc.) requires a very expensive equipment and usually may not provide results for a complex tooth structure. In such situations, Finite Element Analysis (FEA or FEM) is reported to be a very cost-effective tool.[15,16] In literature, FEA has been widely used for: tooth stress analysis,[17] implants design and optimization,[18–20] modelling and optimization of restorations,[21–24] evaluation of fatigue lifetimes before crack failure,[25–27] to name just a few applications.

In analysing the influence of composite restoration on tooth strength, it is important to take into consideration the occurrence of residual (shrinkage) stress.[28] Shrinkage stress has been investigated both numerically and experimentally.[29] Depending on the type of restoration and materials used for it,

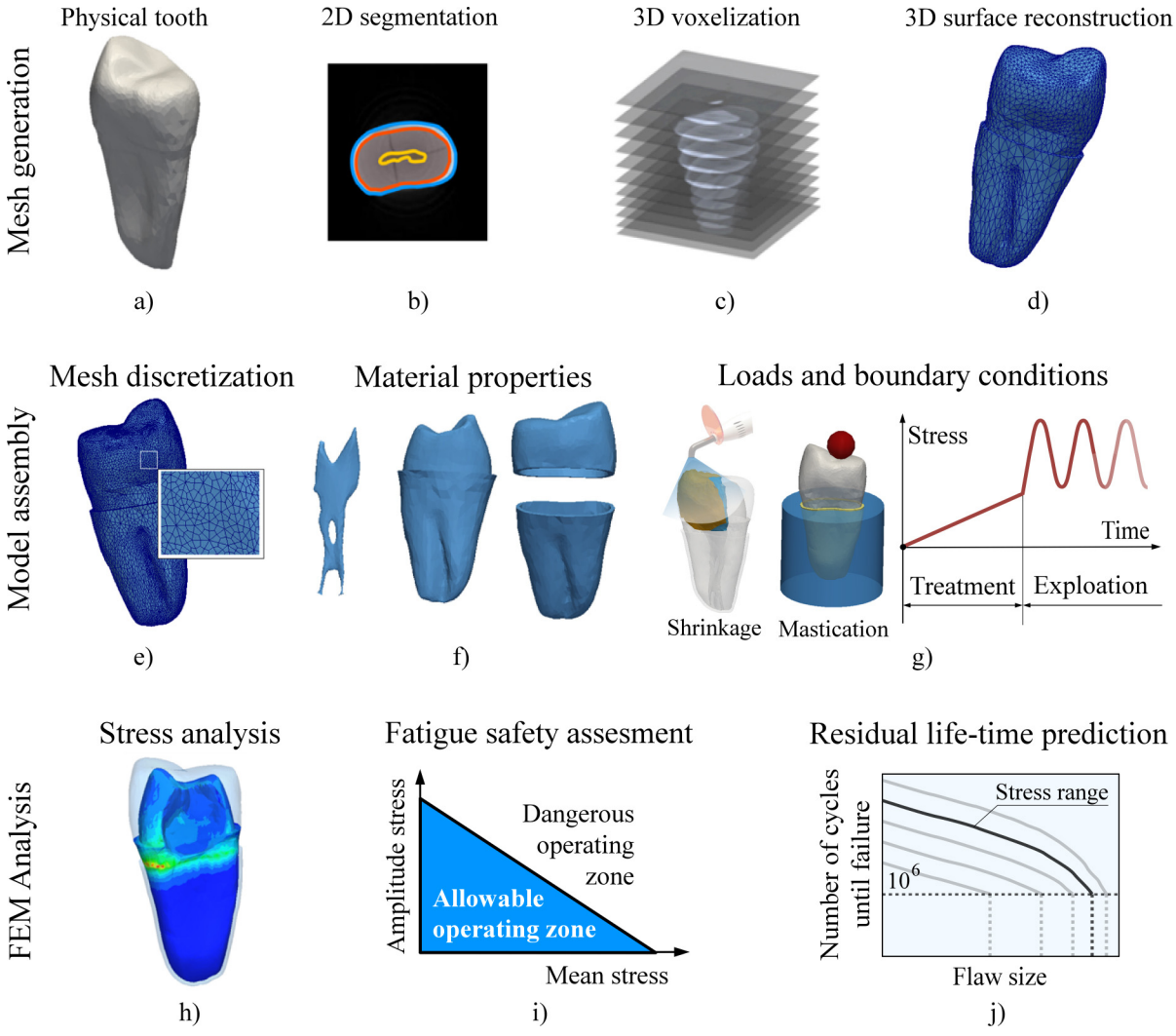

Fig. 1 – Overall procedure.