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Restoration of non-carious cervical lesions
Part II. Restorative material selection to minimise fracture

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ABSTRACT

Objective. It is still largely unknown as to what material parameter requirements would be most suitable to minimise the fracture and maximising the retention rate of the restoration of cervical non-carious lesions (NCCL). The present paper, as a first of its kind, proposes a radical approach to address the problems of material improvement, namely: numerical-based, fracture and damage mechanics materials optimisation engineering. It investigates the influence of the elastic modulus (*E*) on the failure of cervical restorative materials and aims to identify an *E* value that will minimise mechanical failure under clinically realistic loading conditions.
Method. The present work relies on the principle that a more flexible restorative material would partially buffer the local stress concentration. We employ a "most favourable" parametric analysis of the restorative's elastic modulus using a fracture mechanics model embedded into finite element method. The advanced numerical modelling adopts a Rankine and rotating crack material fracture model coupled to a non-linear analysis in an explicit finite element framework.
Results. The present study shows that the restorative materials currently used in non-carious cervical lesions are largely unsuitable in terms of resistance to fracture of the restoration and we suggest that the elastic modulus of such a material should be in the range of 1 GPa. We anticipate that the presented methodology would provide more informative guidelines for the development of dental restorative materials, which could be tailored to specific clinical applications cognisant of the underlying mechanical environment.

1. Introduction

Non-carious cervical lesions (NCCL) are commonly encountered and raise considerable restorative challenges for the dentist. A critical factor for restorative success is represented by the selection of the restorative materials [1]. These issues dictate the restoration's integration in an area of the tooth, which involves multiple biomaterials and experiences complex stresses [2,3].

Currently, the materials of choice indicated for restoring cervical lesions include: glass-ionomer cements, resin-modified glass-ionomer cements, polyacid-modified

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resin-based composites (compomers) and composites resins [4,5]. However, there is no unanimous recommendation for one material or another. This may be, among other reasons, because of a fundamental lack of understanding on how the restorative elastic properties affect the retention rate of cervical restorations.

There is a significant body of literature, which documents the influence of filling material type on the longevity of cervical restorations. Clinical studies have shown repeatedly that restorations of NCCL have inadequate retention rates, with higher percentages of failure at the cervical, compared with the occlusal margins [6–11]. To circumvent the existing shortcomings and improve the clinical longevity of cervical restorations, modified or unmodified preparations [6], layered restorative techniques [1,12] and improvements in the adhesion of the materials [13] have been suggested.

In contrast, the influences of the elastic and fracture properties of the materials are rarely investigated, and often such information has to be inferred from comparative studies involving materials with different properties. This is surprising because the role of mechanical stress is widely accepted as a cause of failure of restorations. It is also well known that the stiffness tensor of the restorative materials considerably affects the stress distribution within the restoration and its mechanical integration with the native tooth [14,15].

There is a generally acknowledged need for different and/or improved restorative materials, which are compatible within the new biomechanical framework imposed by the current paradigm of minimally invasive dentistry concepts [16]. Such novel materials should be better tailored for some specific needs, as for instance use in cervical restoration [5].

The present paper, as a first of its kind, proposes a radical approach to address the problems of material improvement, namely: numerical-based material optimisation engineering. It investigates the influence of the elastic modulus (*E*) on the failure of cervical restorative materials. That is, we aim to identify the “most favourable” selection of *E* value for the restorative material, which will allow it to survive under the unfavourable occlusal loading conditions that may prevail.

This is a continuation our previous work [17] which focused on the influence of cavity size and shape on the failure of GIC restoration in NCCL. It showed occlusal loading direction as a major factor contributing to restoration failure, and that oblique-oriented forces induce tensile stresses on the cervical margin above the strength of the material and bonding.

The present work relies on the principle that a more flexible material would partially buffer the local stress concentration [1,12,15] and hence reduce the likelihood of mechanical failure of the restoration. To implement this principle, we use a parametric analysis of the restorative's elastic modulus using a fracture mechanics model embedded into finite element method. The advanced numerical modelling adopts a Rankine and rotating crack material fracture model coupled to a non-linear analysis in an explicit finite element framework.

2. Materials and method

In this study the goal was to determine the value of *E* of the restorative material at which failure (identified as micro-damage or macroscopic cracking) is avoided under a realistic clinical loading scenario.

We investigate the failure of three types of NCCL restorations when the elastic and fracturing properties of the restorative material are prescribed using actual values, as reported in the literature. Subsequently, we steadily adjust the *E* value of the restorative until the stress profiles shows that mechanical failure is unlikely to occur.

2.1. *Tooth model*

The geometry employed in this study (Fig. 1) was based on the reconstruction of a human permanent lower first premolar, extracted for orthodontic reasons and which was micro-CT scanned using a SkyScan 1072 system (SkyScan, Aartselaar, Belgium). The maximum deviation between the original CT image and reconstructed surface solids was less than 0.6%. The 3D reconstruction methodology is described in detail elsewhere [17]. The generation of the geometry for the plain strain model is described in the first part of this paper [18].

2.2. *Restoration types*

A NCCL (abfractive) wedged-shaped lesion was created on the buccal cervical margin being 1.5 mm deep and 1.5 mm wide in the occluso-cervical direction. These parameters were employed to fit *in vivo* determined dimensions of abfraction lesions [19].

Two filling techniques were chosen for the present work (Fig. 2): (a) single bulk material, namely glass-ionomer (GIC) and (b) a layered technique. The latter consisted of a layer of GIC encompassing a composite bulk. Two thicknesses were considered for the GIC layer: 50 and 150 μm.

2.3. *2D plain strain numeric model and the finite element solver*

The resulting 2D profile was subsequently meshed using a total of 2116 plain strain linear elements and all the interfaces of the model were considered as bonded (Fig. 1b). The region of interest (GIC filling) was meshed using element's size of 0.025 mm in the cervical region and 0.1 mm elements in the occlusal region (Fig. 2a). The reminder of the tooth model was meshed using 0.4 mm linear triangular elements. A mesh-convergence test was then carried out using linear elastic material models under a load of 150 N applied at 40° obliquely on the tip of the buccal cusp to ensure that no further refinement of the mesh is necessary.

Numerical analysis was carried out using ELFEN (Rockfield Software Ltd., Swansea, UK) and employing the discrete solver, which allows automatic transition from continuum to discrete, including crack initiation/propagation, modelling of self-contact in the cracking interface, material softening, and adaptive remesh with data transfer.

In the non-linear finite element fracture analysis presented here, the topological update of the mesh consists in the insertion of a discrete crack when the tensile strength in a principal direction reaches zero, and the crack is orientated orthogonal to this direction. The basis of this model is