X-ray microtomography characterization and mechanical analysis of sealing defects within all-ceramic dental restorations

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Abstract. The present study aims at analysing the impact of defects inside the cement layer of all-ceramic dental restorations on the mechanical behaviour of the dental assembly. This study is lead on simplified dental assemblies. First, X-ray microtomography is performed to visualise the possible defects in a cement layer. Then, a finite element analysis is conducted to understand the mechanical impact of the observed defects. Two kinds of flaws resulting from the polymerization shrinkage of dental cement are observed: spherical voids and a partial debonding. It appears that such imperfections may significantly increase tensile stress within the ceramic coating which can lead to a premature failure of the prosthesis.

Introduction

Because of their thermomechanical properties, their bio-compatibility and their aesthetic, ceramic materials have become popular in modern dentistry. However, those prostheses are prone to brittle fracture due to a tensile stress concentration at the cementation interface [1,2]. The sealing procedure, based on the polymerization of a composite resin, seems to generate a volume contraction due to the transformation of monomers into polymers implying flaws in the cement layer [3]. The present work aims at investigating this phenomenon and particularly its mechanical impact on all-ceramic restorations.

Materials and Methods

Sample preparation. Axisymmetric simplified geometries of a crown bonded to a dental preparation were machined using a CNC milling machine (Lyra-GACD SA). The Vita Enamic® CAD/CAM was used to realize the crown and bovine cortical bone was used to mimic human dentin for the dental preparation. The two parts were sealed using the Kerr Maxcem Elite™ resin cement following clinical guidance.
X-ray microtomography and image processing. The resulting assembly was scanned using a X50CT (NSI). A stack of 1606 pixels x 1368 pixels x 1368 pixels images, with a voxel size of 8.3 µm is obtained. The open source software ImageJ/Fiji with BoneJ plugin is used for image analysis [4,5]. The segmentation and image processing procedure is presented in Fig.1.

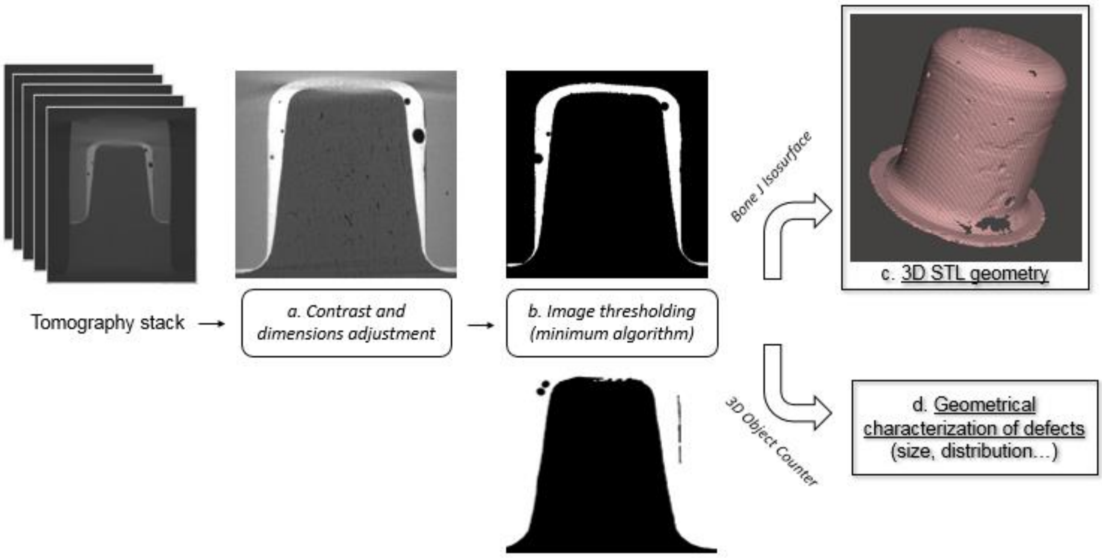

Fig. 1 Image processing procedure

Finite element analysis. Three different axisymmetric models were defined on Abaqus 6.11 (Dassault System). The models are presenting different cement layer geometries: an ideal cement configuration; a geometry with a hole and a partially debonded geometry. The materials were supposed linear elastic, a 50 MPa compression load is applied on the ceramic coating, the layers were linked with tie constraints and the dental preparation is considered fixed on its basis.

Results

Microtomography observations. Two kinds of defects were observed in the cement layer of the assembly: voids and a partial debonding (Fig.2). Thirty-six voids are observed with a volume varying from 1.13 x 10^{-3} mm^3 to 0.131 mm^3. The debonded area is approximately 0.2 mm^2. The total polymerization shrinkage measured is 5.64 %.

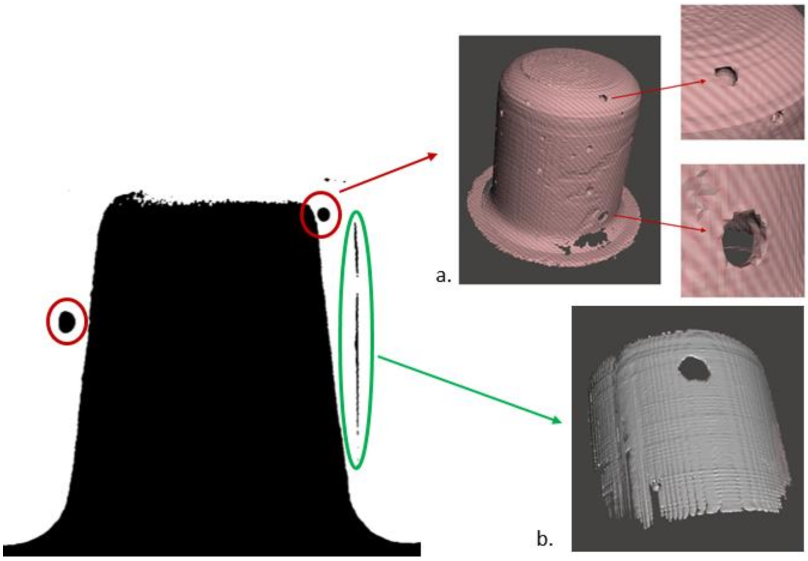

Fig. 2 Defects observations within the cement layer. a) voids, b) partial debonding

Finite element calculation. The same stress field repartition was observed for the three models, with a biaxial tensile stress concentration within the ceramic at the interface with the cement layer. Maximum principal stress measured at this location were 38.10 MPa, 42.94 MPa, 63.56 MPa for the ideal configuration, the void configuration and the debonded configuration, respectively.

Discussion

Dental composite polymerization shrinkage seems to induce voids within the cement layer of the restored tooth. Those defects may generate privileged failure zones in the restoration depending on their location. In fact, when those voids are located at the interface with the prosthesis, the ceramic appends to manage a pure biaxial flexion solicitation whereas in the case of an ideal sealing, its strain is partially damped by the resin cement layer.

Clinically those defects could not be detected and it appears that X-ray microtomography is an efficient way to characterize the cement layer of all-ceramic dental restoration. The presence of randomly sized voids and of a lateral debonding implies that the polymerization shrinkage phenomenon is not homogeneous. The most used model for polymerization shrinkage in dental application considering a homogenous thermal-like contraction can then be reconsidered as it clearly overestimates the residual stress within the assembly.

Conclusions

In this study a new method allowing to characterize the real geometry of the cement layer of a restored tooth has been defined. The first results suggest that there exists several defects within the resin material contributing to a loss of strength of the ceramic prosthesis. The experimental protocol should be used on more assemblies in order to generalize those observations and to better understand the mechanism of ceramic infiltration by polymers during the polymerization process.

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