DENTAL MATERIALS XXX (2018) XXX–XXX

Available online at www.sciencedirect.com

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Mechanical behavior of CAD/CAM occlusal ceramic reconstruction assessed by digital color holography

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ARTICLE INFO

Article history:
Received 21 December 2017
Received in revised form
30 April 2018
Accepted 4 May 2018
Available online xxx

Keywords:
Digital holography
Color holography
V preps
Ceramic occlusal veneer
3D displacement fields
Strain fields
Mechanical behavior

ABSTRACT

Objectives. CAD/CAM ceramic occlusal veneers are increasingly used as therapeutic options. However, little is known about their mechanical behavior under stress, as the response of the prepared tooth that supports it. The aim of this article is to use for the first time 3D color holography to evaluate the behavior of a molar occlusal veneer under stress and the response of the prepared tooth.

Methods. The occlusal surface of a lower molar is prepared to receive a specific monolithic ceramic reconstruction manufactured with a chairside CAD/CAM system. Longitudinally cut samples are used to get a planar object observation and to "look inside" the tooth. A digital holographic set-up permits to obtain the contact-less and one-shot measurement of the three-dimensional displacement field at the surface of the tooth sample; stain fields are evaluated with low noise-sensitive computation.

Results. Figures show the strain fields with micro-strain units and highlight the behavior of the ROI (region of interest) in the three directions of space. The ROI are: the ceramic, the glue junction, the dentin enamel junction, dentin and enamel. The results show an excellent behavior of the restored tooth without areas of excessive stress concentrations, but also a significant involvement of the dentin enamel junction.

Significance. The ceramic occlusal veneer seems to behave in accordance with the biomechanical concepts ensuring the longevity of the reconstituted tooth. 3D holography is a highly recommended method for studying dental biomechanics.

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https://doi.org/10.1016/j.dental.2018.05.007

1. Introduction

Because of their high biocompatibility, pleasing aesthetics [1], the development and the improvement of reliable adhesive bonding techniques [2], ceramics are widely used as restorative materials in dentistry. In parallel, advances in dental CAD/CAM (computerized aided design and computerized aided manufacturing) technologies [3] have catalyzed the developments of the aesthetical ceramic restorations with superior mechanical properties [4,5]. From a mechanical point of view, the possibility to program the thickness of the bonding joint, associated with the precision machining, provides optimization for the accommodation of the stresses by the ceramic [5]. However, if the mechanical properties of the reconstruction and assembly materials seem the essential success elements, the preparation design is a key factor for the long-term success of ceramic coverage restorations [6]. Thus, experimental tests need to be carried out in order to observe the accommodation constraints of bonded ceramic restorations. In the past, researchers developed and used different methodologies to evaluate properties of dental reconstructions. Methods of experimental validation and 3D finite element analysis on interface problems in adhesive reconstructions are still regularly used to reveal differences in tensile and compressive stresses in reconstruction materials and interfaces [7–9].

Especially, indentation was developed to measure the Young's modulus of enamel and dentin [10,11]. Such an approach requires contact of the measuring device with the biological material. However, observing the accommodation constraints of bonded ceramic restorations by optical means, allows knowing if the geometry of the preparation influences the behavior of the material under load. In order to get contactless and full-field inspection of the behavior of dentine or enamel, optical metrology was developed in the past [12–25]. Moiré projection and digital photo elasticity provide images of the inspected surface through the observation of fringe patterns encoding the changes at the surface of the sample [13–23]. These techniques require a preparation of the surface by bonding a specific material playing a revealing role. Coherent metrology through phase shifting ESPI (Electronic Speckle Pattern Interferometry) overcomes such requirement by directly illuminating the surface of the sample with a laser light [24–26]. Even if the tooth surface can be paint in order to enhance the signal-to-noise ratio, no specific material has to be bonded. ESPI can provide full-field measurement of the three-dimensional displacement at the surface of the sample. Such full-field analysis is very useful for comparison with FEM analysis [27–29] because it provides a high density of data points. The drawback is that such measurement is not "one shot" and displacement components have to be measured sequentially; this does not guaranty immunity to mechanical or environmental drifts. This article proposes an experimental approach based on digital three-color holography that yields simultaneous measurements of the 3D displacement field at the surface of the studied sample. The method is based on the use of three laser lines simultaneously illuminating the sample surface along different illumination angles. Three-color digital holograms are then recorded with a color sensor, and the Doppler phase shift along each color is extracted to calculate the 3D displacement fields. In addition, strain fields can be numerically computed.

In this study, tooth samples are submitted to mechanical loads and investigated by digital color holography. The test consist in applying the mechanical load step-by-step. Thus, this is not a cyclic fatiguing test occlusally, because in that case, it would be necessary to make acquisitions of images at the beginning of the experimentation, and then at regular intervals of time. This will be the subject topic of another quite interesting study. In this papers, the distribution of constraints is the main thing to observe and to measure.

The occlusal surface of a lower molar is prepared to receive a specific monolithic ceramic reconstruction. "V preparations" or "V preps" are especially indicated for any type of occlusal surface lesion [30]. So, those reinforced feldspathic restorations are located in a region where occlusal forces are maximal. D. Sutton and H. Stevie first suggested the V prep in the late 1990's for Cerec users [31]. This form of minimally invasive preparations [32], without peripheral preparation, is indicated for all reconstructions of the occlusal surfaces of premolars and molars in cases of carious teeth [33], replacement of prior treatments (amalgam fillings, composite fillings, defective inlays or onlays) and eroded teeth. They can also be performed if preparation is necessary in the case of vertical dimension augmentation [34]. Up to know, this type of preparation has been little described and analyzed. In this study, sample is observed on a sagittal section with the holographic method [35] while it is subjected to an axial strength. The behavior of the ceramic, the glue interface and the prepared tooth are observed simultaneously in the 3 directions of space. This highlights the behavior of the ceramic under duress but also the bonding joint and the response of the dental support, which is the purpose of this study. To the best of our knowledge, this article reports the first use of digital color holography in Odontology.

This paper is organized as follows; Section 2 discusses on materials and methods and describes the optical set-up, Section 3 provides experimental results for the displacement and strain fields, Section 4 proposes an analysis of the results and Section 5 draws the conclusions of the study.

2. Material and methods

2.1. Material

2.1.1. Specimen preparation

As shown in Fig. 1, intact lower molar free of caries have been extracted as part of the routine orthodontic treatment of young healthy patient (aged < 25), it was disinfected and stored in physiological serum with traces of chloroform. The tooth was prepared to receive a V preparation. The entire occlusal surface is reduced by respecting its relief thanks to the use of burr guide (NTi-Kahla GmbH Rotary Dental Instruments, Kahla, Germany, set 1720), for subtracting the same material thickness over the entire occlusal surface, and reproduce its relief.

An optical imprint was taken. The Cerec AC® (Sirona Dental System®, Bensheim, Germany) CAD/CAM was used. The soft-

Please cite this article in press as: Xia H, et al. Mechanical behavior of CAD/CAM occlusal ceramic reconstruction assessed by digital color holography. Dent Mater (2018), https://doi.org/10.1016/j.dental.2018.05.007