Journal of Biomechanics 44 (2011) 1008–1013

Contents lists available at ScienceDirect

Journal of Biomechanics

journal homepage: www.elsevier.com/locate/jbiomech
www.JBiomech.com

Digital image correlation analysis of the load transfer by implant-supported restorations

Rodrigo Tiossi [a], Lianshan Lin [b], Renata C.S. Rodrigues [a], Young C. Heo [b], Heather J. Conrad [c], Maria da Gloria C de Mattos [a], Ricardo F. Ribeiro [a,*], Alex S.L. Fok [b]

[a] Department of Dental Materials and Prosthodontics, Dental School of Ribeirão Preto, University of São Paulo, Av. do Café, s/n, Monte Alegre, 14040-904, Ribeirão Preto, São Paulo, Brazil

[b] Minnesota Dental Research Center for Biomaterials and Biomechanics, School of Dentistry, University of Minnesota, 16-212 Moos Tower, 515 Delaware Street SE, 55455, Minneapolis, MN, USA

[c] Department of Restorative Sciences, School of Dentistry, University of Minnesota, 9-450a Moos Tower, 515 Delaware Street SE, 55455, Minneapolis, MN, USA

ARTICLE INFO

Article history:
Accepted 14 February 2011

Keywords:
Image correlation
Implants
Load transfer
Prosthodontics

ABSTRACT

This study compared splinted and non-splinted implant-supported prosthesis with and without a distal proximal contact using a digital image correlation method. An epoxy resin model was made with acrylic resin replicas of a mandibular first premolar and second molar and with threaded implants replacing the second premolar and first molar. Splinted and non-splinted metal–ceramic screw-retained crowns were fabricated and loaded with and without the presence of the second molar. A single-camera measuring system was used to record the in-plane deformation on the model surface at a frequency of 1.0 Hz under a load from 0 to 250 N. The images were then analyzed with specialist software to determine the direct (horizontal) and shear strains along the model. Not splinting the crowns resulted in higher stress transfer to the supporting implants when the second molar replica was absent. The presence of a second molar and an effective interproximal contact contributed to lower stress transfer to the supporting structures even for non-splinted restorations. Shear strains were higher in the region between the molars when the second molar was absent, regardless of splinting. The opposite was found for the region between the implants, which had higher shear strain values when the second molar was present. When an effective distal contact is absent, non-splinted implant-supported restorations introduce higher direct strains to the supporting structures under loading. Shear strains appear to be dependent also on the region within the model, with different regions showing different trends in strain changes in the absence of an effective distal contact.

1. Introduction

The essential difference between natural teeth and osseointegrated implants is the absence of a periodontal ligament and thus limited micromovement in the latter, which consequently have less favorable distributions of forces (Weinberg, 1993) that concentrate at the crest of the ridge (Rieger et al., 1990). Natural teeth can move by up to 100 μm within its surrounding periodontal ligament, allowing for a certain degree of misfit of a fixed partial denture (FPD). In contrast, an osseointegrated implant has limited movement, less than 10 μm, due solely to bone elasticity (Watanabe et al., 2000). Excessive forces at the implant–bone interface could lead to bone resorption (Riedy et al., 1997).

Numerous prosthetic options are available for dental restoration using multiple adjacent implants. Since complete passivity is difficult to achieve when using splinted restorations supported by multiple implants (Tiossi et al., 2008), some authors suggest restoring adjacent implants individually (Solnit and Schneider, 1998) to allow for a passive fit in the resulting restorations (Guichet et al., 2002). Splinting implant-supported restorations is primarily recommended for load sharing in distributing the antagonistic occlusal forces (Skalak, 1983) so as to reduce the strains transferred to the periodontium (Wylie and Caputo, 1991; Yang et al., 1999). Occlusal overload may induce bone resorption which can lead to marginal bone loss and consequently to implant fractures and implant failure, primarily in the mandibular first molar region (Conrad et al., 2008; Quirynen et al., 1992; Rangert et al., 1995).

The ideal restoration of a partially edentulous space remains controversial as to the number of implants to be placed, the type

* Corresponding author. Tel.: +55 16 36024046; fax: +55 16 3633 0999.
E-mail addresses: rtiossi@yahoo.com (R. Tiossi), linxx643@umn.edu (L. Lin), renata@forp.usp.br (R.C. Rodrigues), heoxx002@umn.edu (Y.C. Heo), conr0094@umn.edu (H.J. Conrad), gloria@forp.usp.br (M.d. de Mattos), rribeiro@forp.usp.br (R.F. Ribeiro), alexfok@umn.edu (A.S. Fok).

0021-9290/$ - see front matter © 2011 Elsevier Ltd. All rights reserved.
doi:10.1016/j.jbiomech.2011.02.015

of implant–abutment connection to select, and whether screw- or cement-retained components should be used (Zarone et al., 2007). Studies are not available to guide clinicians sufficiently in evaluating and choosing many of the possible permutations and combinations of prosthetic designs. In fact, there is no evidence to suggest that implant survival or success is affected by the type of prosthesis (Weber and Sukotjo, 2007). There is thus no consensus on the best prosthetic design for partial rehabilitations with multiple adjacent implants to improve load distribution and decrease stress on the implant–bone interface, with the aim of increasing the implants' survival rate. Although finite element models can simulate the mechanical behavior of many of these prosthetic designs, their validity as a predictive tool needs to be established using experimental data.

Digital image correlation (DIC) is an optical method that has been used to measure the flow of fluid and the surface strain distribution in materials testing (Li et al., 2009). In the latter application, a series of images of the specimen are taken using a charged-coupled device (CCD) camera during loading and the movements of individual spots on the surface of the specimen can be tracked and analyzed using specialist software to determine their displacements. The strains on the surface are then derived from the displacement fields (Li et al., 2009). Compared with strain gauges, therefore, DIC has the advantage of being able to provide full-field strain measurement.

The purpose of this in vitro study was to utilize DIC to analyze strains generated by implants in simulated supporting bone of 2 different prosthetic designs (splinted and non-splinted) under 2 clinical situations (presence or absence of distal interproximal contact to the restoration). Load transfer characteristics of the different prosthetic solutions were analyzed and compared. The null hypothesis was that there would be no differences in the strains generated in the supporting bone between the different prosthetic designs and between the different proximal contact conditions.

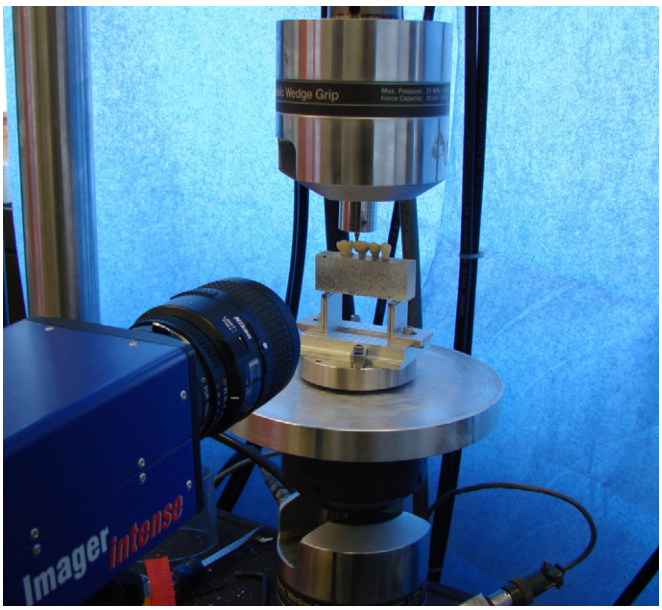

Fig. 1. Experimental setup including the model, CCD camera, loading and supporting devices.

2. Material and methods

A model representing the bone block was fabricated from polymethylmethacrylate resin (Plexiglas®, Altuglas International, PA, USA) with dimensions of $68 \times 25 \times 15$ mm (length, height and depth, respectively). Osteotomies were prepared and a patient-simulating arrangement comprising two $\varnothing 3.75 \times 11$ mm threaded implants (Titamax GT, Neodent, Curitiba-PR, Brazil) were embedded into the bone block model in the second premolar and first molar positions with cyanoacrylate adhesive (Super Bonder; Loctite Brasil Ltd., Itapevi-SP, Brazil) applied on their surface to represent complete integration (Akca and Cehreli, 2008). The model was completed with the placement of resin replicas of a first premolar and a second molar (Odontofix, Ribeirão Preto-SP, Brazil) using the same method as that for the implants.

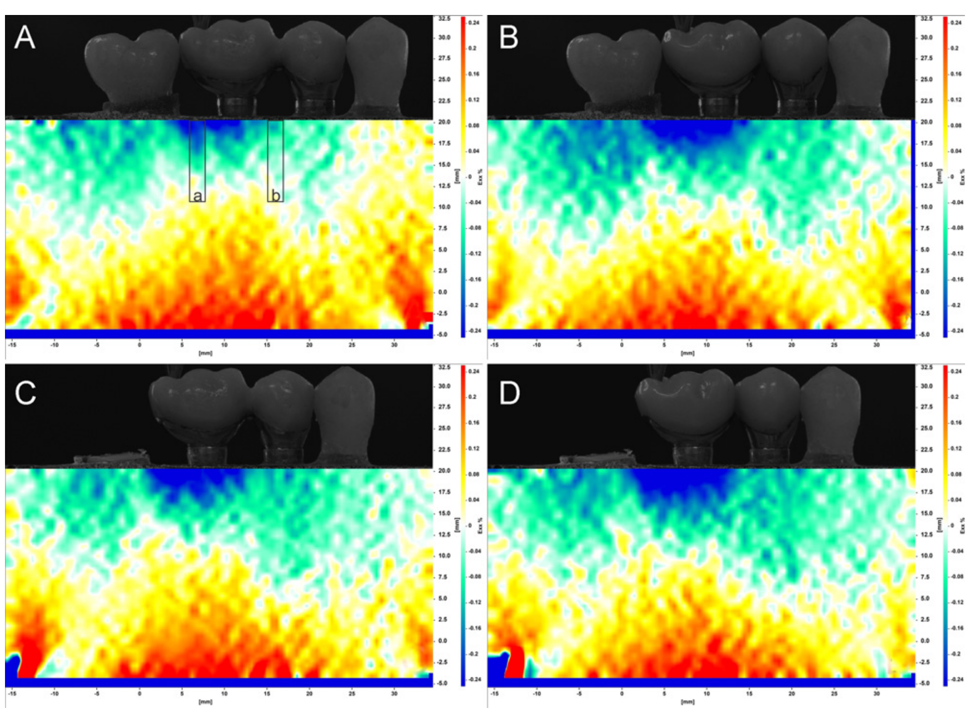

Fig. 2. Strains measured in the horizontal direction (ε_{XX}). (A) Splinted crowns with second molar; (B) non-splinted crowns with second molar; (C) splinted crowns without second molar; and (D) non-splinted crowns without second molar. (a) Region of interest between molars and (b) region of interest between implants.