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Research paper

Biomechanical comparison of implant retained fixed partial dentures with fiber reinforced composite versus conventional metal frameworks: A 3D FEA study

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ABSTRACT

Fiber reinforced composite (FRC) materials have been successfully used in a variety of commercial applications. These materials have also been widely used in dentistry. The use of fiber composite technology in implant prostheses has been previously presented, since they may solve many problems associated with metal alloy frameworks such as corrosion, complexity of fabrication and high cost. The hypothesis of this study was that an FRC framework with lower flexural modulus provides more even stress distribution throughout the implant retained fixed partial dentures (FPDs) than a metal framework does. A 3-dimensional finite element analysis was conducted to evaluate the stress distribution in bone, implant–abutment complex and prosthetic structures. Hence, two distinctly different models of implant retained 3-unit fixed partial dentures, composed of Cr–Co and porcelain (M-FPD model) or FRC and particulate composite (FRC-FPD model) were utilized. In separate load cases, 300 N vertical, 150 N oblique and 60 N horizontal forces were simulated. When the FRC-FPD and M-FPD models were compared, it was found that all investigated stress values in the M-FPD model were higher than the values in the FRC-FPD model except for the stress values in the implant–abutment complex.

It can be concluded that the implant supported FRC-FPD could eliminate the excessive stresses in the bone–implant interface and maintain normal physiological loading of the surrounding bone, therefore minimizing the risk of peri-implant bone loss due to stress-shielding.

1. Introduction

In recent years, as a result of advances in oral implantology the osseointegrated dental implants have been shown to be predictable options for treatments ranging from the replacement of a single tooth tocomplete arch restorations (Christensen, 2002; Pietrabissa et al., 2000). In the last decade, dental implants have been successfully used to support fixed partial dentures (FPD) (Naert et al., 2001).

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Superstructures on dental implants commonly consist of a metal-framework veneered with ceramic facing. In spite of the proven clinical success of metal–ceramic restorations, there has been an increase in the use of metal-free ceramic systems because of their superior esthetics, chemical durability and biocompatibility (DeHoff et al., 2006). A novel alternative to metal–ceramic and full ceramic restorations in implant-supported FPDs is fiber reinforced composite (FRC) designs (Ruyter et al., 1986; Behr et al., 2001). FRC materials, which had been successfully used in a variety of commercial applications, have been more widely used in dentistry. Carbon–graphite fiber-reinforced poly(methyl methacrylate) for complete-arch implant prostheses has been previously presented (Björk et al., 1986; Segerström and Ruyter, 2007). Glass FRC for implant supported fixed prostheses has also been suggested (Behr et al., 2001; Freilich et al., 2002). FRC prostheses have been presented with a framework composed of fiber bundles pre-impregnated with a resin matrix and a veneering composite that covers the FRC framework (Freilich et al., 2000).

Laboratory studies have shown that FRC materials exhibit flexure strength that is greater than or comparable to metal alloys (Anusavice, 1996). Behr et al. (2001) evaluated that the fracture strength of glass FRC FPD on dental implants was almost three times higher than the maximum chewing force measured in young patients with natural dentitions (400 N) (Fontijn-Tekamp et al., 2000).

The use of fiber composite technology for FPDs is a low-cost alternative to metal-alloy, metal–ceramic, or all-ceramic restorations (Fischer et al., 2004). Moreover, FRC has been suggested to absorb energy from the masticatory cycle due to the lower flexural modulus of the material (Meriç et al., 2005). Composite veneer materials have distinct advantages over porcelain veneers; the former are less brittle, do not wear the opposing dentition, and chemically bond to the FRC framework (Freilich et al., 1998). Recently FRC was found to have better stress distribution than other materials, such as glass ceramic, gold, alumina and zirconia (Magne et al., 2002).

The transfer of functional loads and accompanying stress distribution in a bone–implant–prosthesis assembly depends on the physical properties and spatial geometric configuration model of each component. The effects of different prosthetic materials and designs on stress distribution in implant supported prostheses have so far not been reported.

The aim of the present study was to evaluate and compare the effects of the framework and veneering materials on stress distribution of implant retained FPDs in the bone around the implants as well as in the fixture-abutment complex, in the framework and in the veneering part of the prostheses.

2. Materials and methods

To evaluate the stress distribution in and around the bone, the implant–abutment complex and 3 unit FPDs supported by two implants, finite element analysis (FEA) was conducted.

2.1. *Finite element model*

Two three-dimensional finite element models were generated; each representing a 3 unit FPD designed with different materials. In the first model, FPD was constructed with a metal framework and porcelain (M-FPD) and the second model was designed with an FRC framework and particulate composite (FRC-FPD).

The implants were embedded in the first premolar and first molar sites (Fig. 1a). Totally edentulous mandibular male bone was used as the basis of a mandibular finite element model. The modeled section of the mandible was composed as a dense cancellous core surrounded by a thick layer of cortical bone. The average thickness of the cortical bone in the crestal area was 2.0 mm. Serial axial sections in every 0.5 mm of the edentulous mandible was obtained from a NewTom 3G (Quantitative Radiology, Verona, Italy) Cone-Beam CT (CBCT) imaging System. The CBCT images were stored using DICOM 3.0 as a medical image file format and imported into Maxilim (Medicim Company, Mechelen, Belgium) version 2.2.2, 3D medical image processing software. The 3D image of the mandible was imported with the .stl file format into MSC MENTAT (MSC Software Corporation, Santa Ana, CA, USA) version 2005 for pre-processing and modeling.

In the current study, a model of a 13.0 mm long and 4.0 mm in diameter solid-screw Astra Tech implant (Astra-Tech, Astra-Tech AB, Molndal, Sweden) and direct abutment for the Astra implants were selected. The geometry of the implants and abutments was modeled according to engineering drawings by using MSC MENTAT (MSC. Software Corporation, Santa Ana, CA, USA).

A 3 unit FPD consisting of a first premolar abutment, a second premolar pontic, and a first molar abutment was fabricated. In the first model (M-FPD), cobalt–chromium (Bego, Bremen, Germany) was used for the framework (Fig. 1b) and feldisphatic porcelain was used for the veneering material (Fig. 1f). The thickness of the metal framework and porcelain used in this study were 0.5 mm and 1.5 mm respectively and the cement thickness was ignored.

In the second model (FRC-FPD), an anisotropic continuous unidirectional E-glass FRC (everStick, StickTech, Turku, Finland) was selected to construct the framework of the FPD. The design of the fiber reinforced implant prosthesis was obtained from the literature (Freilich et al., 2002). A combination fiber and hybrid composite coping is made to fit over the metal abutment. Veneers were made of isotropic veneering hybrid composite (Estenia, Kuraray; Tokyo, Japan). The composite coping was prepared with horizontal grooves on the facial and lingual surfaces and vertical boxes on the proximal surfaces that allow for adaptation of the unidirectional FRC material (Fig. 1c). The thickness of the coping used in this study was 0.5 mm and the thickness of the luting composite was ignored. Strips of FRC are placed in the copings' proximal boxes, buccal and lingual surfaces, and wrapped around the copings (Fig. 1d). An additional layer was placed perpendicular to the previous layers of FRC (Fig. 1e). 1.5 mm thick hybrid composite veneer was placed over the framework to obtain the full contour of the prosthesis (Fig. 1f). All the final solid meshes were constituted by tetrahedral elements with four nodes by using MSC MARC (MSC. Software Corporation, Santa Ana, CA, USA).