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Properties of axially loaded implant–abutment assemblies using digital holographic interferometry analysis

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ABSTRACT

Objective. The aim of this study was to (i) obtain the force-related interferometric patterns of loaded dental implant–abutment assemblies differing in diameter and brand using digital holographic interferometry (DHI) and (ii) determine the influence of implant diameter on the extent of load-induced implant deformation by quantifying and comparing the obtained interferometric data.

Methods. Experiments included five implant brands (Ankylos, Astra Tech, blueSKY, MIS and Straumann), each represented by a narrow and a wide diameter implant connected to a corresponding abutment. A quasi-Fourier setup with a 25 mW helium–neon laser was used for interferometric measurements in the cervical 5 mm of the implants. Holograms were recorded in two conditions per measurement: a 10 N preloaded and a measuring-force loaded assembly, resulting with an interferogram. This procedure was repeated throughout the whole process of incremental axial loading, from 20 N to 120 N. Each measurement series was repeated three times for each assembly, with complete dismantling of the implant-loading device in between. Additional software analyses calculated deformation data. Deformations were presented as mean values \pm standard deviations. Statistical analysis was performed using linear mixed effects modeling in R's lme4 package.

Results. Implants exhibited linear deformation patterns. The wide diameter group had lower mean deformation values than the narrow diameter group. The diameter significantly affected the deformation throughout loading sessions.

Significance. This study gained *in vitro* implant performance data, compared the deformations in implant bodies and numerically stated the biomechanical benefits of wider diameter implants.

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1. Introduction

The surgical placement of dental implants is the most predictable phase in implant dentistry resulting with successful integration in more than 98% of the cases [1,2]. The long term success of an integrated implant can be assessed by evaluating the surrounding bone level, peri-implant soft tissue, prosthetic superstructure and patient's overall satisfaction [3]. The objective clinical parameters mentioned are interdependent: a standard two-piece implant has an inevitable microgap at the prosthetic interface, thus facilitating bacterial colonization that may result in soft tissue inflammation and crestal remodeling [4,5]. Furthermore, functional loading propagates microgap enlargement [6] and can additionally influence the peri-implant tissue physiology.

Research on implant biomechanics associated load distribution with implant size and shape [7,8]. In finite element analysis (FEA) studies, an increase in implant diameter was demonstrated to cause an exponential decrease of peri-implant bone stress upon loading. In one study [8], the highest stress reduction exhibited (31.5%) was between the 3.6 mm and 4.2 mm diameter implants. Further enlargement of implant diameter resulted in a continuous drop in stress reduction. The same study, however, reported that increasing the implant length did not influence bone stress in the same order of magnitude; the reduction effect was significantly lower. Another observation pertaining to this issue noted that 80–100% of load induced stress was exhibited in the crestal 40% of the fixture, regardless of the implant length [7]. Collectively, these findings emphasize the importance of analysing the loading properties of the cervical part of an implant in the field of implant biomechanics.

A substantial number of studies have analysed the peri-implant bone stress; however, they seldom investigated the changes in the implant–abutment assembly itself [6,9–15]. Most of the analyses were based upon virtually simulated experiments, thus lacking empirical data pertinent for actual performance. In spite of many advantages, FEA can describe the behavior of real 3D structures only to an accuracy depending on the appropriate complexity of the virtual model, size of the mesh, displacement gradient variations and errors in input data. Digital holographic interferometry (DHI) enables a direct insight in rough surface deformation upon loading *in vitro* with submicron accuracy [16]. The method overcomes the mentioned problems by providing continuous, non-destructive and whole-field deformation measurements of actual specimens. Term 'digital' means the employment of a CCD sensor for recording holograms [17] which can then be stored in computer memory and reconstructed either numerically or optically [18,19].

To our knowledge, only a small number of studies used an interferometric approach for evaluating implant biomechanics [6,20,21]. Wahl et al. [6] studied the influence of load application on titanium implant–superstructure interface dislocation using electronic speckle pattern interferometry (ESPI). Three 4.1 mm diameter implants were connected to three different prosthetic superstructures and loaded with a 41.6 N force applied to the palatal cusps of the crowns at a 45° angle using a piezoelectric device. The screw retained

superstructure dislocations at the implant–superstructure interfaces were analysed and quantified, resulting with a mean value of 0.27 μm gap formations. Chorres et al. [20] used holographic interferometry (HI) to compare the load distributions between fully-implant and tooth-implant supported fixed pontics. The authors used three 4.0 mm diameter titanium implants previously placed in the dog mandibles and compared the two types of fixed prostheses loaded with a 10 N force at anterior, midpoint and posterior positions. The qualitative analysis of the holograms obtained showed uniform deflection fringes in fully-implant supported pontics, whereas in case of tooth-implant pontics fringes were not present in dental abutments due to the higher displacement of the teeth than the capacity of the holography set up. Matsumoto et al. [21] investigated implant-induced stress concentration in monkey mandibles using HI. The authors placed a ceramic implant in the second molar position, supporting a fixed partial denture between the fixture and the first and second premolars. The double exposure technique was used to obtain holographic interferograms for various force applications to the superstructure. When vertically loaded at the second premolar point, the bone exhibited the highest stress concentration on the mesial aspect of the pontic, causing a detrimental effect on the bone.

To this date, there has not been an interferometric study that thoroughly analysed loading properties of different implant–abutment assemblies. The purpose of this study was to obtain the interferometric patterns and analyse the deformations in the cervical portions of several implant–abutment assemblies under incremental axial loading by means of digital holographic interferometry. Additionally, our objective was to compare the loading properties of different implant–abutment assemblies based on their diameters.

2. Materials and methods

Experiments included 5 different titanium dental implant brands: Ankylos (Friadent, GmbH, Mannheim, Germany), Astra Tech (Astra Tech AB, Mölndal, Sweden), blueSKY (Bredent GmbH & Co. KG, Senden, Germany), MIS (MIS Implants Technologies Ltd., Bar Lev Industrial Park, Israel) and Straumann (Institut Straumann AG, Basel, Switzerland). Each brand was represented by a narrow and a wide diameter implant connected to a corresponding titanium abutment, as listed in Table 1.

2.1. Loading device

A special set of devices and accessories was designed, fabricated and tested at the Mechanical Properties Research Laboratory (Faculty of Mechanical Engineering and Naval Architecture, Zagreb, Croatia) throughout one year time period prior to this research (Fig. 1a). The basis for the implant loading assembly was a precision fabricated vertical vice with a heavy metal base that minimized undesired movements. First, a metal cylinder was mounted onto the vice bar. Secondly, a high precision digital dynamometer (HBM Kraftaufnehmer U1, Hottinger Baldwin Messtechnik GmbH, Darmstadt, Germany) was attached to the metal cylinder with a large diameter screw.

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