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Stresses and distortions within zirconia-fixed dental prostheses due to the veneering process

Marc Philipp Dittmer, Lothar Borchers, Meike Stiesch, Philipp Kohorst *

Department of Prosthetic Dentistry and Biomedical Materials Science, Hannover Medical School, Carl-Neuberg-Straße 1, 30625 Hannover, Germany

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Abstract

Changes in the marginal and internal fit during manufacture are detrimental to the long-term success of fixed dental prostheses (FDPs). Hence, the aim of this study was to investigate the distortion of four-unit zirconia bridges induced by the veneering process with in vitro and finite element analyses (FEA). Ten all-ceramic FDPs with zirconia frameworks were prepared. The marginal and internal fit of the restorations were determined prior to and after veneering by means of a replica technique. Additionally, a three-dimensional finite element model of the restoration was constructed and cooling after the veneering process was virtually simulated. Statistical analysis revealed significant changes in the marginal and internal fit due to the veneering process. FEA verified these observations and displayed tensile stresses (up to 65 MPa) within the framework and compressive stresses (up to 10 MPa) within the veneering layer. The present study showed that stresses and distortions, occurring due to the veneering process, may influence the marginal and internal fit and therefore the clinical success of dental restorations.

Keywords: Zirconia; FDP; Distortion; Finite element analysis; Thermal stress

1. Introduction

The disadvantages of ceramometal fixed dental prostheses (FDPs) have led to the implementation of new high-performance ceramics for dental applications in recent years. Besides esthetics, these materials offer excellent biocompatibility, low plaque accumulation and low thermal conductivity. The remarkable strength characteristic of the new all-ceramic systems, especially of oxide ceramics like yttria-stabilized polycrystalline tetragonal zirconia (Y-TZP), is well-documented in the literature [1,2] and even the high-loaded molar region can apparently be treated with wide-span all-ceramic restorations [3,4]. The good esthetics of these restorations is achieved by successive application and firing of layers of translucent veneering dentin and enamel porcelains onto a core made of zirconia. Y-TZP owes its high strength to the so-called transformation reinforcement, a complex mechanism involving transformation from tetragonal to monoclinic structure and associated with a local 4% increase in volume [5]. This transformation takes place at a crack tip and results in compressive stresses within the matrix, thereby increasing the energy necessary for further crack growth. Due to its distinctive strength and hardness, Y-TZP is usually processed in a presintered porous state by means of computer-aided design/computer aided manufacturing (CAD/CAM) systems and sintered after machining with a subsequent increase in density [6].

Besides load-bearing capacity, fitting accuracy and especially marginal fit are crucial aspects for the long-term success of dental restorations. However, restorations can be distorted during the veneering process [7–9]. Distortions may create a space between restoration and preparation. As this space increases, luting material is exposed to the oral environment. Because of the solubility of most dental cements, bacterial plaque can accumulate in this defective area, which, in turn, may cause marginal parodontitis,

* Corresponding author. Tel.: +49 511 532 4798; fax: +49 511 532 4790.
E-mail address: Kohorst.Philipp@mh-hannover.de (P. Kohorst).

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due to irritation of adjacent tissues or secondary caries with subsequent pulpitis [10]. Additionally, deformations in the horizontal plane of the ceramic frameworks may clinically result in occlusal displacement of the FDPs. Furthermore, increasing the space between abutment teeth and copings in the axial wall area can reduce the load-bearing capacity of all-ceramic restorations [11].

Various studies have investigated the influence of the veneering process on the marginal accuracy of ceramometal restorations. It has been reported that the frameworks of these ceramometal restorations have a poorer marginal and internal fit after the application and firing of veneering porcelain compared to the initial fit of the castings [8,12,13]. In contrast, there have been few investigations of the effect of porcelain firing on the marginal fit of all-ceramic restorations. For crowns made of a feldspathic ceramic or glass-infiltrated alumina, Balkaya et al. [7] reported that the addition of porcelain caused a distortion to the copings' margins. Castellani et al. [14] also found significant distortions of the marginal area due to the veneering process for single crowns manufactured with different all-ceramic systems. They even found that evaluated all-ceramic crowns were more sensitive to repeated porcelain firing cycles than comparable ceramometal restorations. However, in the present study all-ceramic restorations made of zirconia were evaluated which show different mechanical and thermal characteristics and therefore probably different values of distortions due to the veneering process.

The thermal incompatibility between the framework material (metal or ceramic) and the veneering porcelain is thought to be one of the most likely reasons for the resulting distortions [7,9]. During the veneering process, all-ceramic restorations are fired several hundred degrees above the glass transition temperature, up to the sintering temperature of the veneering ceramic. After this temperature has been reached, the restorations are removed from the furnace and air-cooled at rates of approximately $600\,^{\circ}\mathrm{C\,min^{-1}}$. In layered structures with different thermal expansion coefficients (TECs), this cooling may result in substantial stress [15]. These stresses can cause deformation of the restoration [9], immediate cracking of the porcelain [15] or an increase in the probability of fracture during functional loading of the restoration [16]. In dentistry, thermal incompatibility is often characterized by the difference between the TEC of the core material (α_{core}) and that of the veneering porcelain ($\alpha_{veneering}$); this difference is termed mismatch ($\Delta\alpha = \alpha_{core} - \alpha_{veneering}$) [17]. For layered restorations, a positive $\Delta\alpha$ causes formation of tensile stress within the framework, while the veneering ceramic is subjected to compressive stresses; a negative $\Delta\alpha$ will produce the reverse effect [18]. Dental manufacturers have developed all-ceramic systems featuring veneering ceramics of slightly lower TECs than that of the framework, resulting in a positive mismatch of the TECs. This positive mismatch is expected to induce a beneficial compression stress on the veneering porcelain layer. However, though ceramics exhibit high strength when subjected to compressive stresses, they are weak under tensile stress. This susceptibility to tensile stresses may weaken the ceramic core and so consequently the whole all-ceramic restoration. Hence, in a current study investigating stresses within standardized specimens, Aboushelib et al. [18] postulated that it would be desirable to minimize the thermal mismatch as much as possible, especially for all-ceramic zirconia restorations.

The objective of the present investigation was to test the hypothesis that with a four-unit zirconia FDP the veneering process induces distortions which influence the restoration's marginal and internal fit. Additionally, finite element analysis of the veneering process was performed to verify the in vitro findings and to obtain detailed information about resulting distortions and stresses within the restoration.

2. Materials and methods

2.1. Manufacture of the zirconia cores

In an upper jaw resin model (Frasaco OK 119, A-3 T, Franz Sachs & Co., Tettnang, Germany), teeth 24 and 27 were prepared to accommodate a four-unit all-ceramic FDP with a zirconia framework (Fig. 1). To duplicate this situation, a stainless steel master model (Wiron 99, Bego, Bremen, Germany) was made. By means of an individual impression of this master model, a stone cast (Fuji Rock, GC, Leuven, Belgium) was produced and used as the basis for manufacturing the zirconia bridge frameworks. Ten cores were prepared in partially sintered zirconia (ZS-Blanks, KaVo, Biberach, Germany) by means of a CAD/CAM system (Everest, KaVo, Biberach, Germany), repeatedly using the same data set obtained during scanning (active triangulation and stripe pattern) of the stone cast. The TEC of the used zirconia material was $10.0 \times 10^{-6}\,\mathrm{K^{-1}}$ according to the manufacturer. The dimensions of all frames were practically the same, with the connector width and height differing by less than 0.1 mm between frameworks. The wall thickness of the abutment crowns amounted to 0.6 mm. Following firing, the frameworks were tried on the master model. If necessary, the fit was corrected with a fine bur (grit size 46 μm, Brasseler, Lemgo, Germany) under water cooling and light pressure.

2.2. Determination of marginal and internal fit

For the determination of marginal and internal fit, the retainers of the FDPs were filled with light body silicone (Dimension Garant L, 3M ESPE, Seefeld, Germany); then the frameworks were placed onto the abutment teeth and loaded with a force of 50 N from the occlusal direction. After the light body silicone had set, the frameworks were removed from the master model while the thin silicone films remained on the abutment teeth. The silicone films representing the space between abutment teeth and bridge retainers were then stabilized by a contrasting heavy body