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# Effect of geometry on deformation of anterior implant-supported zirconia frameworks: An *in vitro* study using digital image correlation

*Nuno Calha DDM* [a], *Ana Messias DDM* [a,b,*], *Fernando Guerra PhD* [a,b], *Beatriz Martinho DDM* [a], *Maria Augusta Neto PhD* [b], *Pedro Nicolau PhD* [a,b]

[a] *Department of Dentistry, Faculty of Medicine, University of Coimbra, Portugal*
[b] *Centre for Mechanical Engineering, University of Coimbra, Portugal*

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ABSTRACT

*Purpose:* To evaluate the effect of geometry on the displacement and the strain distribution of anterior implant-supported zirconia frameworks under static load using the 3D digital image correlation method.
*Methods:* Two groups (n = 5) of 4-unit zirconia frameworks were produced by CAD/CAM for the implant-abutment assembly. Group 1 comprised five straight configuration frameworks and group 2 consisted of five curved configuration frameworks. Specimens were cemented and submitted to static load up to 200 N. Displacements were captured with two high-speed photographic cameras and analyzed with video correlation system in three spacial axes U, V, W. Statistical analysis was made using the nonparametric Mann–Whitney test.
*Results:* Up to 150 N loads, the vertical displacements (V axis) were statistically higher for curved frameworks (−267.83 ± 23.76 μm), when compared to the straight frameworks (−120.73 ± 36.17 μm) (p = 0.008), as well as anterior displacements in the W transformed axis (589.55 ± 64.51 μm *vs* 224.29 ± 50.38 μm for the curved and straight frameworks), respectively (p = 0.008). The mean von Mises strains over the surface frameworks were statistically higher for the curved frameworks under any load.
*Conclusion:* Within the limitations of this *in vitro* study, it is possible to conclude that the geometric configuration influences the deformation of 4-unit anterior frameworks under static load. The higher strain distribution and micro-movements of the curved frameworks reflect less rigidity and increased risk of fractures associated to FPDs.


* *Corresponding author at*: Área de Medicina Dentária da Faculdade de Medicina da Universidade de Coimbra, Avenida Bissaya Barreto, Blocos de Celas—HUC, 3030 075 Coimbra, Portugal. Fax: +351 239402910.
E-mail address: ana.messias@uc.pt (A. Messias).
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## 1. Introduction

The final goal of implant supported rehabilitations is an aesthetic and, most of all, functional treatment, preventing any component from possible collapse, while being biocompatible. Notwithstanding that, biomechanical complications like veneering porcelain chipping, screw loosening or fracture and framework fractures have been addressed as the major causes for failure of prosthetic treatments, especially in the particular case of multi-unit restorations.

One important factor that has been linked to the biomechanical success of fixed partial dentures (FPDs) is the material used for framework fabrication. Ideally, frameworks should be biocompatible, resistant, accurately fit to implants and abutments [1] and able to optimize the aesthetic result of the restoration while dissipating stresses created within and transferred to the implant and bone-implant interface upon load [2].

The search for a strong, yet aesthetic material with which to fabricate FPDs has been ongoing for many years. For most of time the standard has been porcelain-fused-to-metal based restorations [3]. Initially, gold alloy was the most frequently used material for framework fabrication, but due to its high cost, alternative alloys were introduced in dentistry, including cobalt–chromium, silver–palladium, and titanium alloys [4]. More recently, all-ceramic restorations are increasingly used as an alternative to metal-ceramic restorations due to their favorable aesthetics and biocompatibility [5–8].

Thanks to CAD/CAM technology, high-strength ceramic materials can be milled with accuracy using standardized manufacturing processes and reduced production costs [9–11]. In particular, zirconia has been widely used as a first option in frameworks of FDPs due to its unique aesthetic potential and described mechanical properties. Zirconia has a flexural strength of 900–1400MPa and fracture toughness up to $10 MPa/m^{-0.5}$, meaning that it is significantly more resistant to growth of small cracks than any other ceramic system [8,9,12]. Prevention of crack propagation is the best predictor of success of a dental material and is crucial in situations of high occlusal demand as those encountered in the anterior region [12].

Also, the reported elastic modulus of zirconia of 210GPa compared to that of a 12% Au–Ag–Pd alloy (86GPa) [13] is expected to improve the rigidity of the framework thus reducing the distortion under functional loads [14], which means that a zirconia framework may have the potential to reduce the amount of bulk in the substructure leaving more space for ceramic veneering [15] thus better aesthetic results.

This pursue for mimesis has led to an exponential increase in the use of zirconia as framework material for FPDs [16,17], relying on the reported strength of zirconia to propose connector size reduction regarding other ceramic systems and to propose a reduction in the thickness of the framework in comparison to porcelain-fused-to-metal based restorations [18].

Nonetheless, the literature is not consistent on the evaluation of the performance of zirconia-based restorations. Cohesive fractures of the veneering ceramic (chipping) remain one of the most common clinical failure types with zirconia FDPs [19–21], and occurs more often than in metal–ceramic restorations [6,22,23].

Regarding the origin of the veneer chipping, several reasons have been reported: low fracture toughness; [24] thickness of the porcelain; [25] inconsistency or differences in thermal expansion between materials; [26] inadequate cooling rate; [27] processing techniques; [21] phase transformation; [28] low thermal diffusivity of zirconia; [25] insufficient support of the porcelain by the framework [29,30]. However, the mechanism of chipping is complex, multifactorial and still not fully understood [31]. The first step to understanding the occurrence of chipping events consist in studying the influence of framework design factors, namely the shape of geometrical configuration (straight or with round curvature), the thickness or connector volume, the deformation and residual stress that eventually are transmitted to the veneering material [32].

We hypothesized that the geometric shape of zirconia frameworks influences the displacement and strain distributions of implant-supported FPDs. This study aims at the evaluation of the effect of zirconia framework arch geometry on displacement and strain distributions of an anterior implant-supported cemented FPD, during loading, using the 3D digital image correlation (DIC) method.

## 2. Materials and methods

Two Astra Tech OsseoSpeed™ 4.0S implants with 13mm length (ref. 24989, Astra Tech Implant System™, Sweden) were embedded in a rectangular block of Technovit® 4000 (Heraeus Kulzer, Wehrheim Germany), a modified polyester-based resin with inorganic fillers for improved hardness, low shrinkage and excellent adhesion to metal surfaces. Even though the modulus of elasticity of this cold embedding resin is low (≈2000–2200MPa), other important mechanical properties for experimental testing such as density ($1.5 g/cm^3$) or compression strength (280MPa) [33] are similar to those of human bone ($1.9 g/cm^3$ and 100–230MPa, respectively) [34,35]. Implants were placed parallel and 17mm apart, reproducing implant positioning for a four-unit anterior fixed partial prosthesis.

Two TiDesign™ 3.5/4.0 titanium abutments (ref. 24285, Astra Tech Implant System™, Sweden) were connected to the implants and screwed at 20Ncm with a torque wrench according to the instructions of the manufacturer and the access to the prosthetic screw sealed with polytetrafluoroethylene.

Two groups (n=5) of 4-unit zirconia frameworks were then produced by CAD/CAM for the single implant-abutment assembly using the software InLab 3.88 and the InLab MC XL milling and grinding unit (Sirona Dental Systems GmbH, Germany). Geometrical differences within frameworks of each group were limited to variations of the milling process. Group 1 comprised five straight configuration frameworks and group 2 consisted of five curved configuration frameworks. All frameworks were designed maintaining constant thickness of the copings and cervical collar (0.5mm) [36]. Other characteristics of the frameworks such as connector area or arch radius are summarized in Table 1.

The acrylic block and the 10 frameworks were air-sprayed with airbrush pro-color ink (Hansa Airbrush, Norderstedt,

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