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Research Article

Evaluation of Zirconia and Cobalt-Chrome for Custom-Milled Framework Design for an Implant-Supported Full-Arch Fixed Dental Prosthesis: A Finite Element Analysis

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ABSTRACT

The demands for aesthetics in implant-supported full-arch prosthesis increased the use of zirconia as framework material due to its aesthetics, biocompatibility and high survival rate. The aim of this study was to compare the mechanical response of Zirconia and CoCr custom-milled framework indicated for maxillary prosthetic rehabilitations using the Finite Element Method. To perform this simulation, a custom-milled framework design for an implant-supported full-arch fixed dental prosthesis was used. The geometries of bone, prosthesis, implants, abutments and prosthetic screw were modelled. The mechanical properties for each isotropic and homogeneous material were simulated. Two frameworks were simulated (YZTP and CoCr Alloy). A load of 500 N load was applied on the occlusal surface of the right upper first molar. The results were analysed in terms of displacement, von Mises stress and microstrain. After the simulation processing, it was not possible to observe difference for prosthesis displacement or stress concentration regarding the framework material. The use of YTZP exhibited the lowest stress magnitude for implant (60 MPa) near the load application site, in comparison with the metallic framework (76 MPa in the same region). The same behaviour was calculated for the microstrain results in peri-implant region. The use of YZTP to perform a custom-milled framework design for an implant-supported full-arch fixed dental prosthesis may have acceptable mechanical response for the analysed structures.

Introduction

Zirconia (YTZP) is currently being used in implant dentistry for the fabrication of implant abutments, single crowns, fixed dental prostheses, and even full-arch dental prostheses using the CAD/CAM technology. An alternative restorative approach to the implant supported full-arch prosthesis is a designed and manufactured monolithic zirconia prosthesis. The monolithic nature results in no dissimilar interfaces, and thus minimizes fracture and/or chipping events, creates a greater volume of material to improve the structural properties of the individual prosthesis, and enables efficient fabrication and care delivery through CAD/CAM manufacturing [1].

In order to promote a better aesthetics for the treatment, due to the zirconia opacity, the framework can present an anatomic contour with a partially cut back and veneered with feldspathic porcelain. The incisal edge should be in zirconia to avoid chipping of the feldspathic ceramic [2]. This cut-back design has some advantages, including a faster fabrication, acceptable dental aesthetics; superior strength, durability and wear characteristics; superior fit due to digital fabrication; availability of a permanent digital file for future reproduction;

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opportunity for digital fabrication of a prototype in resin; superior biocompatibility compared with metal alloys; reduced plaque accumulation and favorable soft tissue response [3, 4].

A case series involving 17 edentulous jaws restored with monolithic zirconia full-arch rehabilitation opposing complete dentures reported a favorable behaviour after 1-year [5]. Regarding the biomechanical behaviour from this treatment modality, it was reported that the use of prosthetic material of high elastic modulus and high flexural strength as zirconia optimized the stress distribution [6]. The literature reports that the biomechanical responses of zirconia-based full-arch prosthesis can be affected by different implant configurations (numbers and distributions) and that, increasing the number of supporting implants reduces the loading on each implant [7]. Comparing with titanium framework, the use of zirconia presents a similar biomechanical behaviour for mandibular prostheses without significant increase the amount of stress concentration [8]. In addition, the weight of the zirconia framework with buccal porcelain is not a negative factor and is not able to generate harmful values of peri-implant bone strain [9].

The use of a custom-milled design with buccal cut-back can improve the mechanical response for metal-plastic prostheses. However, the aesthetics can be negatively affected [10]. For this reason, the present study aimed to compare the mechanical response of Zirconia and CoCr custom-milled frameworks indicated for maxillary prosthetic rehabilitations using the Finite Element Method.

Materials and Methods

A full skull model was selected from a database and exported in STEP format to a computer-aided-design software (Rhinoceros Version 4.0 SR8, McNeel North America, Seattle, WA, USA) [10]. The maxilla was sectioned with a cutplane in the region of the anterior nasal spine. Next, an edentulous maxilla was constructed following the main anatomical characteristics of a healthy bone (size, shape and absence of pathology). The cortical bone was modelled with 1 mm thickness in juxtaposition with cancellous bone. A 3D (three-dimensional) volumetric model of the bone was then modelled based on the surface created by the curve network automatically generated with a reverse engineering tool [9].

External hexagon implants (10 mm × 4.1 mm) were subsequently modelled. The external thread diameter was established according to the dimensions provided by the manufacturer (as technology Titanium Fix, São José dos Campos, Brazil), and the platform determined in 4.1 mm in diameter such as a conventional regular implant. The external hexagon presented 0.7 mm high. A mini conical abutment indicated for the screw retained prosthesis was modelled for each implant. The abutments presented centralized insertion with 2.5 × 4 mm. A 3D abutment screw was modelled for each abutment, with a prosthetic screw on top of it [9].

Based on a generic maxillary arch, a full arch implant retained prosthesis was constructed with the following design: a machinable framework with palatal face of all teeth made from the same material of the framework and a 4.1 mm coping screw for each abutment. An example of this treatment modality can be observed in (Figure 1). The veneering aesthetics presented 1 mm of thickness and was limited to the buccal face of the teeth for this prosthesis [9]. Each solid geometry was imported to the analysis software (ANSYS 19.2, ANSYS Inc., Houston, TX, USA) in STEP format and tetrahedral elements formed the mesh. A convergence test of 10% determined the total number of tetrahedral elements and nodes. The mesh (Figure 2) was composed by 743712 nodes and 424264 tetrahedral elements, with the maximum element size of 0.2 mm and an aspect ratio of 1.63 [9].

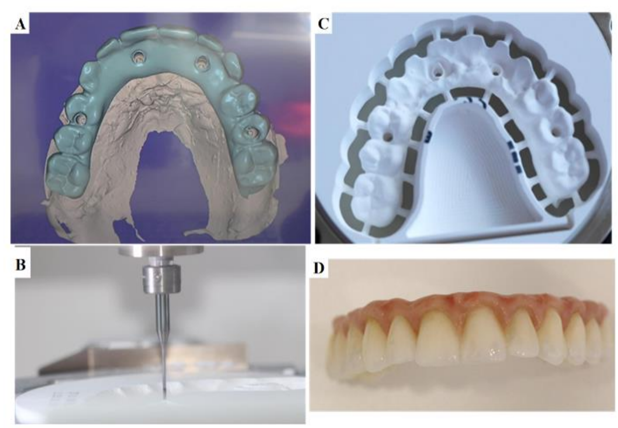

Figure 1: Example of prosthesis milled in zirconia. **A)** CAD planning, **B)** Milling process, **C)** Pre-sintered zirconia aspect after milling and **D)** Final prosthesis with sintered zirconia veneered with an aesthetic porcelain.

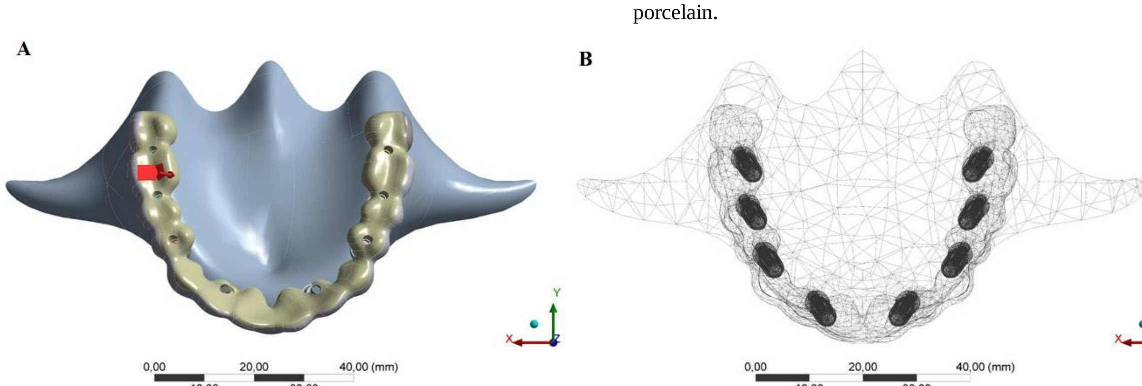

Figure 2: A) 3D model with the load (500 N) application and **B)** Mesh division for the numerical simulation.

The materials mechanical properties were assigned to each solid component with isotropic and homogeneous behaviour. The interfaces were considered ideal and the implants fully osseointegrated. The mechanical properties of the materials are summarized in (Table 1). The cortical bone base was fixed and a masticatory load of 500 N was applied on the occlusal surface of the right upper first molar. The results were analysed in terms of displacement, von Mises stress and microstrain.

Table 1: Mechanical properties of the materials used in the computational analysis.

Material	Elastic Modulus (GPa)	Poisson ratio
CoCr	220	0.30
YTZP	190	0.30
Titanium	110	0.3
Porcelain	50	0.25
Cortical Bone	13	0.3
Trabecular Bone	1.3	0.3

Results

The generated stress values in the maxilla as a function of both restorative materials were plotted in colorimetric graphs in (Figures 3-6). It was possible to observe that the YTZP prosthesis, showed similar trends of displacement in comparison with CoCr. The same behaviour was observed for the stress in the framework. Moreover, the YTZP showed a reduced concentration of peri-implant strain in the region between the distal implants near the load application. The mini-conical abutment showed a higher stress concentration when CoCr was used.

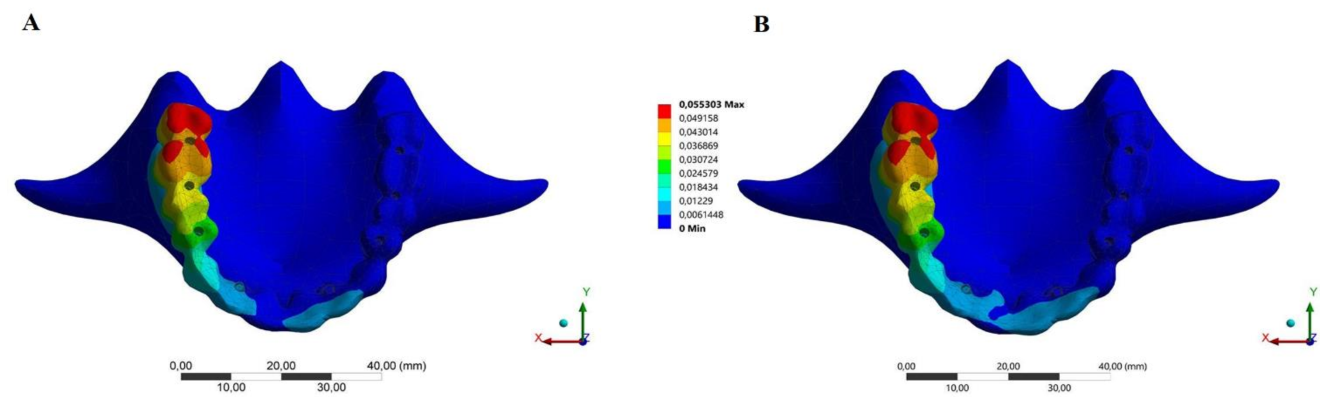

Figure 3: Total displacement results in **A)** Zirconia and **B)** CoCr frameworks.

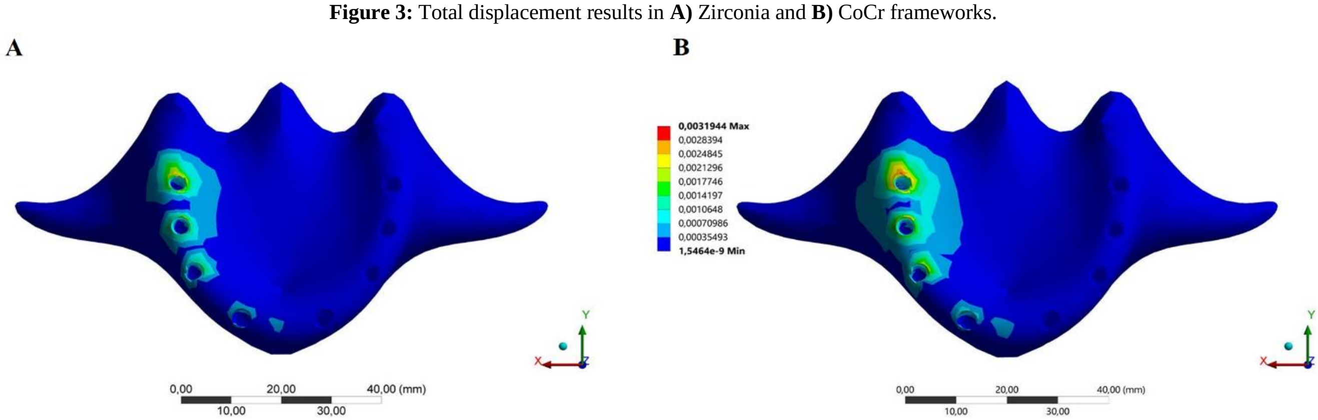

Figure 4: Bone microstrain results in **A)** Zirconia and **B)** CoCr frameworks.

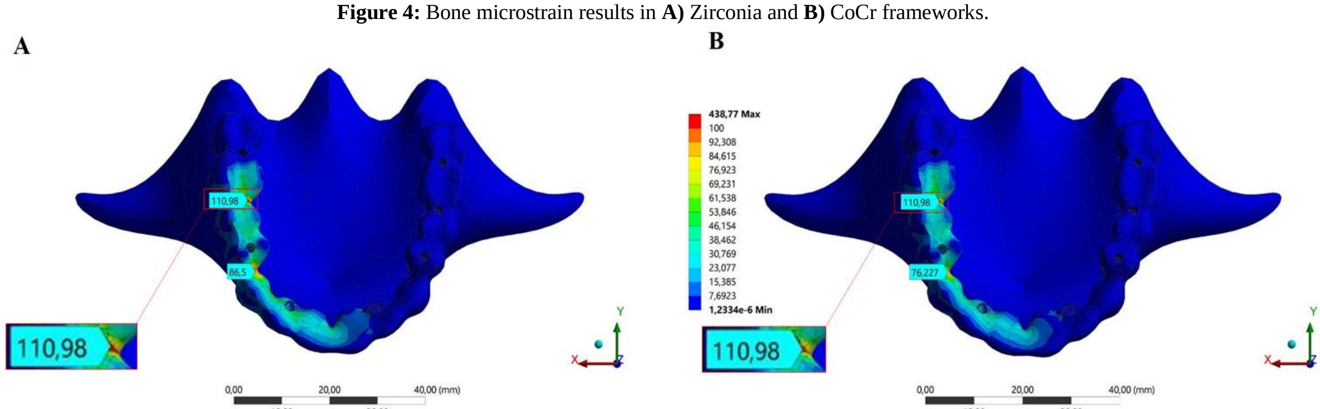

Figure 5: Von mises stress in the prosthesis with **A)** Zirconia and **B)** CoCr frameworks.

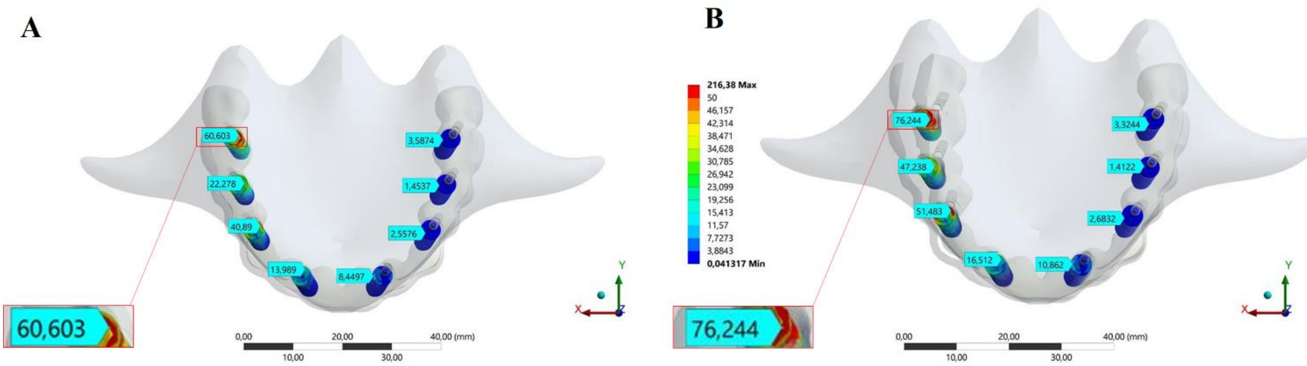

Figure 6: Von mises stress in the implants with **A)** Zirconia and **B)** CoCr frameworks.

According to the Wolff's law, strain values below 50 mm/mm are able to promote bone remodeling by disuse, and values above 3000 mm/mm are able to promote bone remodeling by micro-damage [11]. Results shows that both materials showed strain peaks below 2800.

Discussion

This study compared the mechanical response of YTZP, and CoCr custom-milled frameworks indicated for maxillary prosthetic rehabilitations using the Finite Element Method. The results showed that the framework material had influence in the prosthesis mechanical response.

Previous clinical studies reported an acceptable longevity and success for implant-supported full arch custom-milled zirconia prosthesis [1, 12]. According to previous authors, seven patients rated their satisfaction with their restoration as 10/10, one as 9/10 and one as 8/10, and all patients answered that they would recommend the treatment [12]. These results can be reinforced with the numerical simulation presented in this study, showing a promising mechanical behaviour with acceptable stress levels for this treatment modality in comparison with the CoCr alloy. Another possible advantage of this treatment modality is that the digital workflow enhanced patient acceptance and comfort. The application of digital workflow using intraoral digital scanner instead of conventional impression has the potential to reduce the chairside time and simplify the prosthodontic protocol. This treatment modality can achieve survival rates of 100% after clinical follow-up of 2 years, associated with a lower bone microstrain and lower stress concentration in the implants, as shown, respectively, in (Figures 4 & 6) [13].

According to a previous report, for fixed partial denture, the stress value of the retaining screw can be reduced using stiffer framework materials as CoCr and Zirconia [14]. The authors assumed that due to the materials' capability to resist bending and to support more stress concentration, it leads to a lower stress transmission to the peri-implant bone tissue. The present study is in agreement with this statement, since YTZP was simulated with lower elastic modulus than CoCr and that both groups showed the reported behaviour.

Due to the presence of an aesthetic veneering material (porcelain), in clinical conditions, the masticatory cycles involving dynamic loads may result in different biomechanical behaviour and stress distribution for bi-layered all-ceramic restorations, resulting in different failure modes [15]. In addition, the residual stresses generated due to linear contraction after the cooling process can reduce the treatment longevity [15]. The residual stress will also be present for the CoCr framework; however, the comparison between both materials has been not related in literature yet. It is important to follow the manufacturer's recommendation and use a porcelain with corresponding properties according to the framework material.

The region of stress concentration in the bone, implants, abutments and prosthesis was in the area of the load application and in the most distal region, on the same side of the load application. These regions were directly subjected to the applied load, so they received the highest stresses. Stresses presented in the implants represent areas of the highest torque and stress concentrations, caused by levering effects. These results were in agreement with previous reports that evaluated YTZP complete prosthesis in the mandibular arch [6].

The cut-back design has already been reported as an advantageous design when associated with titanium alloy [9]. However, there is no report in the literature that have evaluated this treatment modality for CoCr alloy and YTZP. It is possible to note that the use of YTZP can provide an improved mechanical response and an aesthetic treatment at the same time. However, it is important to note that the YTZP can be susceptible to the slow crack growth at aging process, which cannot be a problem for metal alloys, for example [16]. For this reason, fatigue data should be evaluated in full-arch rehabilitations in further studies considering clinical data and long-term evaluation [17].

Conclusion

The use of YTZP to perform a custom-milled framework design for an implant-supported full-arch fixed dental prosthesis presents acceptable mechanical response during the incidence of masticatory loads.

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