Influence of Ceramic Materials on Biomechanical Behavior of Implant Supported Fixed Prosthesis with Hybrid Abutment

Keywords

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Authors

Dr. João Paulo Mendes Tribst*
(DDS, MSc, PhD student)

Dr. Amanda Maria de Oliveira Dal Piva*
(DDS, MSc, PhD student)

Prof. Mutlu Özcan§
(DDs, MSc, PhD, Professor)

Prof. Alexandre Luiz Souto Borges*
(DDS, MSc, PhD, Professor)

Prof. Marco Antonio Bottino*
(DDS, MSc, PhD, Professor)

Address for Correspondence

Dr. Amanda Maria de Oliveira Dal Piva*

Email: amodalpiva@gmail.com

* *Post-Graduate Program in Restorative Dentistry (Prosthodontic), Department of Dental Materials and Prosthodontics, São Paulo State University (Unesp/SJC), Institute of Science and Technology, Brazil*

§ *University of Zürich, Dental Materials Unit, Center for Dental and Oral Medicine, Clinic for Fixed and Removable Prosthodontics and Dental Materials Science, Zurich, Switzerland*

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ABSTRACT

Purpose: This study evaluated the stress distribution in different cement-retained implant-supported prostheses with a hybrid abutment. Materials and Methods: Two factors were evaluated: restorative material for the crown and hybrid abutment - zirconia, lithium disilicate and hybrid ceramic, yielding 9 combinations. For finite element analysis, a monolithic crown cemented on a hybrid abutment was modeled and cemented on a titanium base (Ti base). An oblique load (45°, 300 N) was applied to the fossa bottom and system fixation occurred on the bone's base. Results: Each structure was evaluated separately to find the possible weaknesses in geometry and failure criteria. In this context, results demonstrated a significant decrease of maximum principal and von-Mises stresses concentration when crowns with high elastic modulus are cemented onto a hybrid abutment with lower elastic modulus. Conclusions: Considering this theoretical study for a Morse taper implant, the association of a rigid crown with a more resilient hybrid abutment reduces the tensile stress concentration in the restoration cervical region.

INTRODUCTION

Dental ceramics have excellent mechanical properties,[1] aesthetics,[2] biocompatibility and chemical stability,[1,3] promoting excellent clinical performance to this material[4] in manufacturing dental prostheses. Zirconia stabilized by yttria (Y_2O_3), also known as Y-TZP (yttria tetragonal zirconia polycrystals), has an interesting combination of properties among ceramic materials such as high fracture toughness,[5] high hardness and wear resistance, chemical stability and biocompatibility.[6] The transformation toughness mechanism of Y-TZP, which is responsible for high resistance to fracture, allows the preparation of partial fixed prostheses and prosthetic abutments for implants.[1]

Lithium disilicate is a type of ceramic containing vitreous phase and lithium oxide in its composition, unlike polycrystalline ceramics such as zirconia, whose composition is formed by sintered crystals and absence of a vitreous matrix.[5] Although lithium disilicate has an elastic modulus of 64 GPa[7] and fracture strength lower than Y-TZP (210-400 GPa and 700 GPa, respectively), it is able to offer a more appropriate aesthetic result when resistance is not the most relevant factor. Hybrid ceramics that are polymer infiltrated instead of glass matrix have recently been introduced on the market.[8] Due to the hybrid ceramic's elastic modulus (32 GPa) being lower than other ceramics,[7] low hardness[9] and possibility to obtain fast milling, among its indications are tooth and implant-supported crowns.[10] Also, zirconia and lithium disilicate crowns present high success rates as implant supported prosthesis.[11,12]

This study aimed to evaluate the influence of materials' elastic modulus on the stress distribution of (Morse taper) cement-retained implant-supported prostheses to hybrid abutments. Recent studies have shown that there is no significant difference for the influence of prosthetic connection on peri-implant tissue in mechanical terms.[13-15] However, the literature is quite concise in demonstrating that bacterial infiltrate for implants with a conical connection are practically non-existent.[16,17] Better sealing and less marginal maladjustment[17] associated with factors such as improved torque holding capacity and favorable aesthetics[18] contribute to the increased use of Morse taper implants used.

In order to improve aesthetics of implant crowns, the titanium base was developed to allow less influence of metal on the peri-implant soft tissues, preserving the "pink smile" aesthetics.[20] However, clinical studies have not presented a statistical difference between the abutment material (metal or zirconia) in the color of peri-implant tissues,[20] with positive patient feedback in both cases.[20,21] Yet, the proposal to use a ceramic abutment containing a metallic base only seems possible due to the possibility of cementation in an extra-oral environment, which would not cause intra-sulcular excess cement, and would allow for adequate polishing prior to installation

To overcome the aesthetic influence of metal abutment in peri-implant soft tissue color[20,22] and maladaptation problems of the ceramic abutments,[19] a hybrid abutment was proposed by cementing a ceramic mesostructure onto a titanium base. However, among many ceramic materials available on the market, there is no basic guide for the correct material choice to obtain the mesostructure with the best combination of the ceramic material to be used in the crown. A lack of information is available on hybrid abutments. This approach is suggested to present mechanical properties similar to titanium abutments.[23-25] However, further investigations are necessary to define its potential and limitations of materials and hybrid abutments.[25] Therefore, this study aimed to evaluate the influence of materials' elastic modulus on the stress distribution of cement-retained implant-supported prostheses to hybrid abutments. The null hypothesis was that the combination of ceramic materials with different elastic properties do not influence stress distribution.

MATERIALS AND METHODS

FINITE ELEMENT ANALYSIS (FEA)

Pre-processing

This study was conducted by finite element analysis methodology, which is a mathematical method used to evaluate stress distribution in oral implant systems.[26] A tridimensional (3D) structure was modeled to represent a two piece prosthetic solution, composed by a ceramic crown *(Figure 1a)* and a ceramic mesostructure *(Figure 1c)* over a titanium base *(Figure 1e)*. Both cement layers present in this restoration were modeled *(Figure 1b, d)* in order to simulate clinical reality as closely as possible. This set was then screwed *(Figure 1f)* onto a Morse taper implant *(Figure 1g)*, as shown in Figure 1.

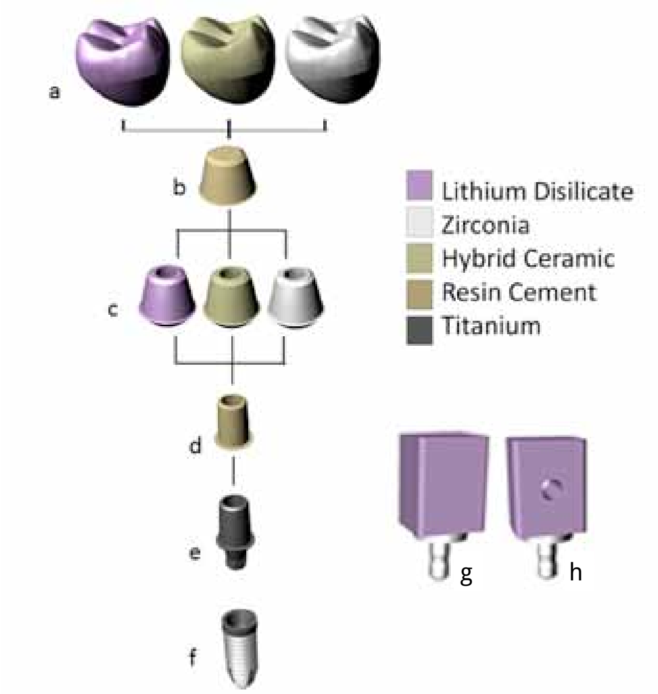

Figure 1: Schematic illustration of the sequential procedures. (a) Ceramic crown. (b) Cement layer between crown and mesostructure. (c) Mesostructure. (d) Cement layer between mesostructure and base. (e) Base. (f) Morse taper implant. (g) Ceramic block indicated for the manufacturing of monolithic crowns. (h) Perforated blocks used in the manufacturing of mesostructures.

All structures were modeled using CAD Rhinoceros software (version 4.0SR8; McNeel North America, Seattle, WA). Resin cement for cement layers was considered with 0.3 mm thickness.[27] The base (NP 4.5 x 5 mm) and Morse taper implant (3.75 x 11 mm) followed the manufacturer's dimensions (Conexão Sistemas de Prótese, Arujá, SP, Brazil).

Analyzing two factors: crown and mesostructure (MS) materials (each one had 3 levels), totaling 9 combinations of different ceramics. Next, solids were exported to analysis software (ANSYS 17.2, ANSYS Inc., Houston, TX, USA) in STEP format. The external surface of the bone model was fixed in all directions (boundary condition), a static load (300 N, 30°) according to ISO 14801: 2012 for dental implants was applied in central fossa and mesh was created with 517,220 nodes and 266,440 tetrahedral elements (after 10% mesh convergence test).[28] All materials were considered isotropic, linearly elastic and homogeneous. No-separation contacts were considered between ceramic/resin cement and resin cement/abutment, in which the target and contact surfaces were tied for the remainder of the analysis.[29] For titanium interfaces the frictional contact was used with friction coefficient (μ) set in 0.3.[30] Between implant and bone, the bonded contact was used simulating a complete osseointegration.[28] Three ceramic materials were used for the ceramic crown and the hybrid abutment: zirconia (Z), lithium disilicate (D) and hybrid ceramic (H). The materials' elastic modulus and Poisson ratio were obtained from literature *(Table 1)*.[1,7,31,32] Results of stress distribution according to von-Mises criteria are shown through color graphics with a respective scale in megapascals (MPa). Von-Mises criteria is commonly used for stress distribution through structures in dental implant studies;[33,34] therefore, this criteria was chosen to facilitate comparisons. Figure 1g and 1h represents the ceramic blocks indicated for the manufacturing of crown and mesostructure, respectively. Further, one-way Analysis of variance (ANOVA) and Tukey test (all, p=0.05) were used to evaluate the tensile stress peaks in the crown and in the abutment according to the groups distribution *(Table 2)*.

Table 1. Distribution of the materials' mechanical properties.

Structure/ material	Elastic modulus (GPa)	Poisson ratio
Zirconia[1]	220	0.3
Lithium Disilicate[7]	63.9	0.22
Hybrid Ceramic[11]	34.7	0.28
Cortical Bone[31]	13.7	0.3
Spongy Bone[31]	1.37	0.3
Resinous Cement[32]	7.5	0.25

Table 2. 1-way ANOVA and post-hoc analysis for the maximum principal stress in the crown and von-Mises stress in the abutment according to the group's distribution (α=5%). Similar superscript letters indicate no statistically significant difference within columns.

			Maximum principal stress in the crown intaglio surface (p=0.000)		Von-Mises stress in the abutment cervical region (p=0.000)	
Group	**Crown material**	**Mesostructure material**	**Mean±SD**	**Minimum-Maximum**	**Mean±SD**	**Minimum-Maximum**
ZL	**Zirconia**	**lithium disilicate**	55.54^{C}±15.78	39.8-71.2	18.01^{B}±3.40	14.61-21.41
ZZ		**Zirconia**	50.32^{C}±14.98	35.40-65.2	19.92^{B}±2.76	17.02-22.65
ZH		**Hybrid ceramic**	68.62^{D}±26.03	42.61-94.63	16.37^{D}±2.49	13.88-18.86
LL	**Lithium disilicate**	**lithium disilicate**	55.52^{C}±13.15	42.35-68.65	18.11^{B}±3.46	14.65-21.57
LZ		**Zirconia**	50.51B^{C}±19.65	30.91-70.11	19.66^{B}±3.33	16.33-22.99
LH		**Hybrid ceramic**	56.26^{C}±16.49	39.71-72.69	17.10^{C}±4.9	12.23-22.12
HL	**Hybrid ceramic**	**lithium disilicate**	47.79^{B}±16.23	31.56-64.02	18.88^{B}±2.98	15.9-21.21
HZ		**Zirconia**	48.82^{B}±18.28	30.6-67.12	17.42^{C}±2.17	15.23-19.57
HH		**Hybrid ceramic**	43.68^{A}±35.45	8.23-79.13	29.78^{A}±7.23	22.51-36.93

RESULTS

Stress distribution through the structures is shown according to the maximum principal stress in the crown and von-Mises stress for the abutment *(Figure 2)*. In the colorimetric graphics, it is possible to observe that more stress concentration in the cervical region occurs inversely proportional to the elastic modulus of the crown, and directly to the elastic modulus of the hybrid abutment. The tensile stress peak occurs at the cervical area of the intaglio surface of the crown. With von-Mises stress criteria analyzing the hybrid abutment, all groups present probability of failure in the cervical region of metallic connection. Table 2 summarizes the statistical analysis of stress peaks in the crown and abutment. 1-way ANOVA showed significant difference on the stress distribution between the evaluated combinations.

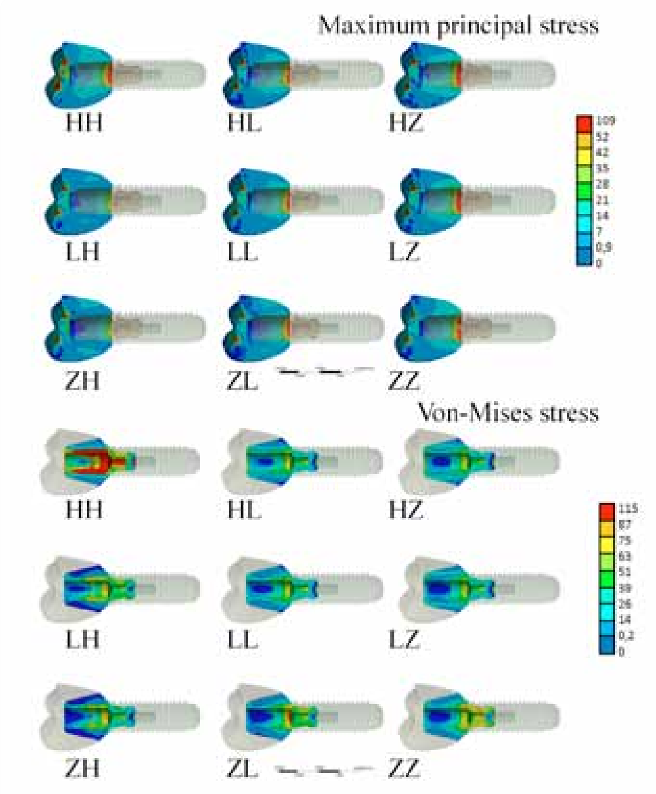

Figure 2: Maximum Principal stress (MPa) in the crown and Von-Mises stress (MPa) in the hybrid abutment.

Lower stress concentration occurs with zirconia crowns, and hybrid abutment for crowns with lower elastic modulus. Figure 3 summarizes the stress distribution homogeneity using histogram graphs, showing the density of stress data (vertical) for magnitude (horizontal). The more the curve is displaced to the right, the higher the stress concentration. While the higher the curve, the greater the homogeneity of stress distribution.

DISCUSSION

Although a titanium base presents aesthetic aspects, its strength is lower than an entirely metallic abutment, but it is superior to an all-ceramic alternative.[35] Thus, the combination of crown and hybrid abutment (ceramic mesostructure cemented onto titanium base) should not allow stress concentration in a titanium base, which would cause a decrease in resistance.

This manuscript has analyzed a technique to perform implant supported crowns that require two machinable blocks for their manufacture *(Figure 1)*. The hypothesis of this investigation was rejected due to the mechanical response of the restoration was being influenced by the different combinations of ceramics crowns and hybrid abutment. Although this is a theoretical study with ideal adhesion conditions for all groups (which does not happen clinically), it has scientific value based on the results analysis in function of the material mechanics.[28]

By analyzing the results of this study, in Figure 2 and 3 it is possible to notice that the stress concentration behaves in a similar way for all combinations: the use of higher elastic modulus for the crown associated with lower elastic modulus for hybrid abutment, the greater homogeneity in the stress distribution in the cervical region with lower stress peaks.

The increased homogeneity in stress distribution allowed an improved reliability due to the mechanical response which is more easily predictable using this finite element calculation.[36] In addition, the lower stress peak means that with the same occlusal force, less damage may be notable due to stress concentration being directly proportional to the crack propagation and ceramic failure.[37,38]

The fracture of ceramics in service occurs with little or no plastic deformation when cracks propagate in an unstable manner under applied tensile stresses. Fracture occurs when the stress intensity factor at the crack tip reaches a critical level, defined by a combination of applied stress, crack length and a dimensionless constant. In this case, the applied stress is dependent on the materials combination.[37]

Another aspect to be considered is the possibility of reduced damage to the abutment, since a failure in this region would mean total repetition of the procedure, with a loss of the crown even if remaining intact (unless the laboratory has stored the individual machining file of that case, which would make it possible to make an identical crown). Regardless of the solution, the fracture in this region would be complex.

A previous study showed that for the same crown material, the use of a zirconia hybrid abutment significantly increased the resistance of the restoration when compared with a lithium disilicate hybrid abutment.[24] This finding was in agreement with the results herein, that demonstrate that the stress generated in these abutments differ significantly when placed under the same restorative material of the crown.

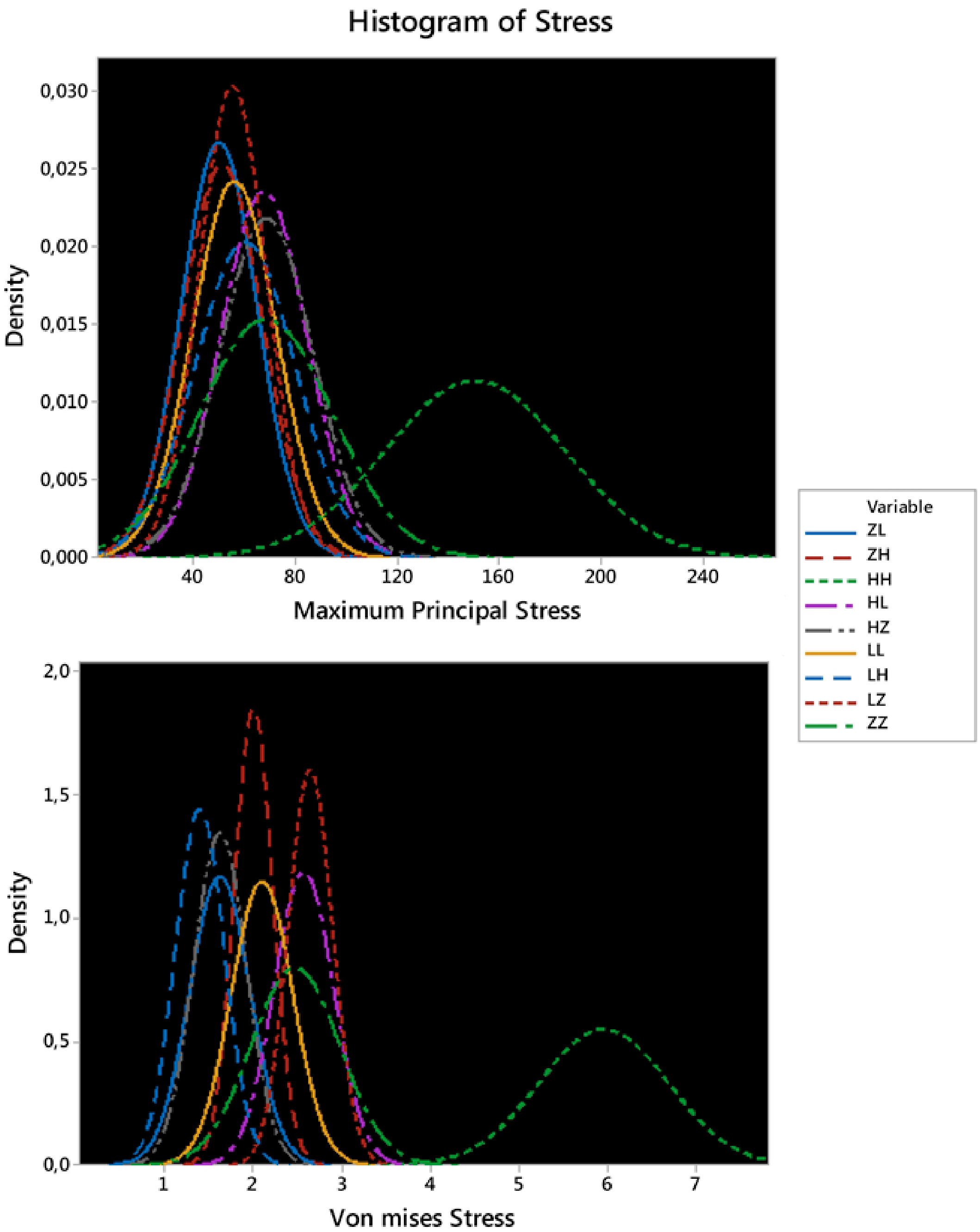

Figure 3: Histogram graphs for the stress distribution (MPa) in the crown and in the hybrid abutment.

Although the materials with high elastic modulus concentrated more stress, they could present an improved fatigue life justified due to the gradient of elastic modulus, improved resilience and toughness.[24,28,38] Nonetheless, the rehabilitation with hybrid abutment and ceramic monolithic crown has no reports in the literature indicating which type of failure is expected clinically. Thus, a zirconia structure, even if it has high resistance, can be affected by defects in the adhesive interface due to the greater stress concentration on its surface.[28,38]

Although laboratory tests are necessary to understand the reliability and wear of this new restorative modality, the results demonstrate that the more resilient the hybrid abutment, the lower tensile stress will be generated in the cervical region. Therefore, a flexible mesostructure seems to be quite interesting because it reduces the stress concentration in its structure, despite concentrating more stress in the titanium base.

Considering the maximum load necessary to fracture the hybrid abutments, the literature reports that the lithium disilicate promotes improved results for the manufacturing of the mesostructure. However, the load was applied directly to the abutments, without the presence of a cemented crown.[39] The results herein also showed that the presence of the crown may modify the mechanical response of the restoration. Likewise, the use of two-piece zirconia restoration already reduces its life in fatigue by 50% in comparison with one-piece zirconia restoration.[40] Therefore it is important for the clinician to know how to choose the ideal combination of ceramics that reduces the stress generated in the system and not simply repeat the choice of ceramics used for hybrid abutment and crown.[28]

Accordingly, the use of a zirconia crown associated with a mesostructure in hybrid ceramic seems to be one of the best combinations, since this becomes more similar to the bio-inspired crowns or even similar to the natural tooth.[28,41] This fact enables higher stress concentration in the crown with lower stress in the emergence profile region of the hybrid abutment. Despite the analogy with the natural tooth, a restoration built on implants has limitations such as the absence of natural dampening of the periodontal ligament.

CONCLUSION

Considering this theoretical study for Morse taper implant, the association of a rigid crown with a resilient hybrid abutment reduces the tensile stress concentration in the restoration cervical region.

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