Effect of platform connection and abutment material on stress distribution in single anterior implant-supported restorations: A nonlinear 3-dimensional finite element analysis

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Statement of problem. Although various abutment connections and materials have recently been introduced, insufficient data exist regarding the effect of stress distribution on their mechanical performance.

Purpose. The purpose of this study was to investigate the effect of different abutment materials and platform connections on stress distribution in single anterior implant-supported restorations with the finite element method.

Material and methods. Nine experimental groups were modeled from the combination of 3 platform connections (external hexagon, internal hexagon, and Morse tapered) and 3 abutment materials (titanium, zirconia, and hybrid) as follows: external hexagon-titanium, external hexagon-zirconia, external hexagon-hybrid, internal hexagon-titanium, internal hexagon-zirconia, internal hexagon-hybrid, Morse tapered-titanium, Morse tapered-zirconia, and Morse tapered-hybrid. Finite element models consisted of a 4×13-mm implant, anatomic abutment, and lithium disilicate central incisor crown cemented over the abutment. The 49 N occlusal loading was applied in 6 steps to simulate the incisal guidance. Equivalent von Mises stress (σ_{vM}) was used for both the qualitative and quantitative evaluation of the implant and abutment in all the groups and the maximum (σ_{max}) and minimum (σ_{min}) principal stresses for the numerical comparison of the zirconia parts.

Results. The highest abutment σ_{vM} occurred in the Morse-tapered groups and the lowest in the external hexagon–hybrid, internal hexagon–titanium, and internal hexagon–hybrid groups. The σ_{max} and σ_{min} values were lower in the hybrid groups than in the zirconia groups. The stress distribution concentrated in the abutment-implant interface in all the groups, regardless of the platform connection or abutment material.

Conclusions. The platform connection influenced the stress on abutments more than the abutment material. The stress values for implants were similar among different platform connections, but greater stress concentrations were observed in internal connections. (J Prosthet Dent 2014;112:1096-1102)

Clinical Implications

For anterior implant-supported restorations, regardless of the platform connection, a zirconia abutment attached to a titanium base or a titanium abutment provides better mechanical behavior than pure zirconia abutments.

Because of its esthetic and functional requirements, the maxillary anterior single crown is still one of the most challenging restorations. The replacement of missing teeth with dental implants is well documented as a feasible treatment with high success rates.[1,2] Nevertheless, esthetic enhancements are still needed, mainly in

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patients with a high smile line.[3,4] The outcome of an esthetic implant can be improved by overcoming the optical problem of the gray discoloration of the marginal periimplant mucosa caused by titanium (Ti) abutments.[5] Therefore, a ceramic abutment (CerAdapt; Nobel Biocare) was introduced.[6-8] The esthetic benefits of ceramic abutments over metal abutments have been well documented in clinical and in vitro studies, although, their mechanical performance is still of concern.[3,9-14] Recent analysis of the mechanical performance of zirconia (Zr) abutments with external or internal connections has revealed lower fracture resistance than Ti abutments, especially with internal connections.[15-21]

Internal connection provides joint stability and better resistance against rotational and lateral movements than external connections.[22-25] However, the abutment's projection into the implant may lead to greater stress concentration due to the thinner abutment and implant walls at the interface.[26] Moreover, fractures of ceramic internal connection abutments have been reported both clinically and in vitro.[12,17,18,20,26] To overcome the fragile properties of Zr at the implant-abutment interface, the 2-piece hybrid (H) Ti-Zr abutment was developed with a Ti base attached to a Zr abutment body.[17,27] Zr is milled onto the Ti base that is screwed onto the implant.[28] Joint stability is improved by the internal design made of Ti alloy, and the ceramic body above the implant platform enhances the esthetics. In contrast to ceramic abutments, the H abutment presented better fatigue strength, which suggests improved mechanical performance.[15,17,18,27]

Despite recent in vitro results with H Ti-Zr abutments, the biomechanical behavior of these components and the different platform connection interfaces is still not well explored. In addition, the use of virtual biomechanical analyses such as the finite element analysis (FEA) can be applied to understand the behavior of structure stress, which cannot be obtained from mechanical testing.[29,30] The aim of this study, therefore, was to evaluate the effect of different combinations of platform connections and abutment materials on the distribution of stresses in the abutment and implants of single implant-supported anterior restorations by using 3-dimensional (3D) FEA.

MATERIAL AND METHODS

Experimental design

Nine 3D anterior maxilla segments were created based on a cone-beam computed tomographic image (i-CAT Cone Beam 3D Dental Imaging System; Imaging Sciences International). Each model consisted of a dental implant developed from the geometry of a 4×13-mm implant (Titamax Ex; Neodent) with different platform connections: external hexagon (EH) or internal hexagon (IH), and Morse tapered (MT) with the same macrogeometry (EH, IH, and MT) and a central incisor lithium disilicate crown cemented over Ti, Zr, or H abutments (Table I). With the aid of 3D computer-aided design software (SolidWorks 2013; Dassault Systèmes SolidWorks Corp), the 9 experimental models (Fig. 1) were obtained by combining platform connections and abutment materials (EHTi, EHZr, EHH, IHTi, IHZr, IHH, MTTi, MTZr, MTH). FEA was used to determine the maximum (tensile) and minimum (compressive) principal stress values for Zr and H Ti-Zr abutments and the von Mises stress for all abutments and implants.

Numerical analysis

All the models were then exported to FEA software (ANSYS Workbench 14 FEA; Swanson Analysis Inc) for biomechanical analysis. The crowns, abutments, screws, implants, and compact and cancellous bone were considered to be isotropic, homogenous, and linearly elastic (Table II). Discrete finite element meshes were generated by using 10-node quadratic tetrahedral elements with 3 degrees of freedom per node. After convergence analysis[31] (6%), the value of the mesh size was 0.7 mm. The models presented a number of elements that ranged from 91 085 to 93 819 and a number of nodes that ranged from 159 965 to 164 975. The boundary conditions were defined by fixing the mesial and distal exterior surfaces of the bony segment in all directions. Immediate loading was simulated by using nonlinear frictional contact elements with a friction coefficient (μ) of 0.3 between the bone and the implant.[32] Occlusal loading was applied to the palatal surface of the lithium disilicate crown at 6 different aligned contact areas obtained for the purpose of simulating the excursive movement of the incisal guide. The 49 N loading was applied at 45 degrees relative to the implant long axis.[33] The maximum (σ_{max}) and minimum (σ_{min}) principal stresses values were obtained for abutment comparison among Zr and H Ti-Zr H groups. Equivalent von Mises (σ_{vM}) stress criteria for abutment and implant numerical and color-coded comparison were obtained for all models.

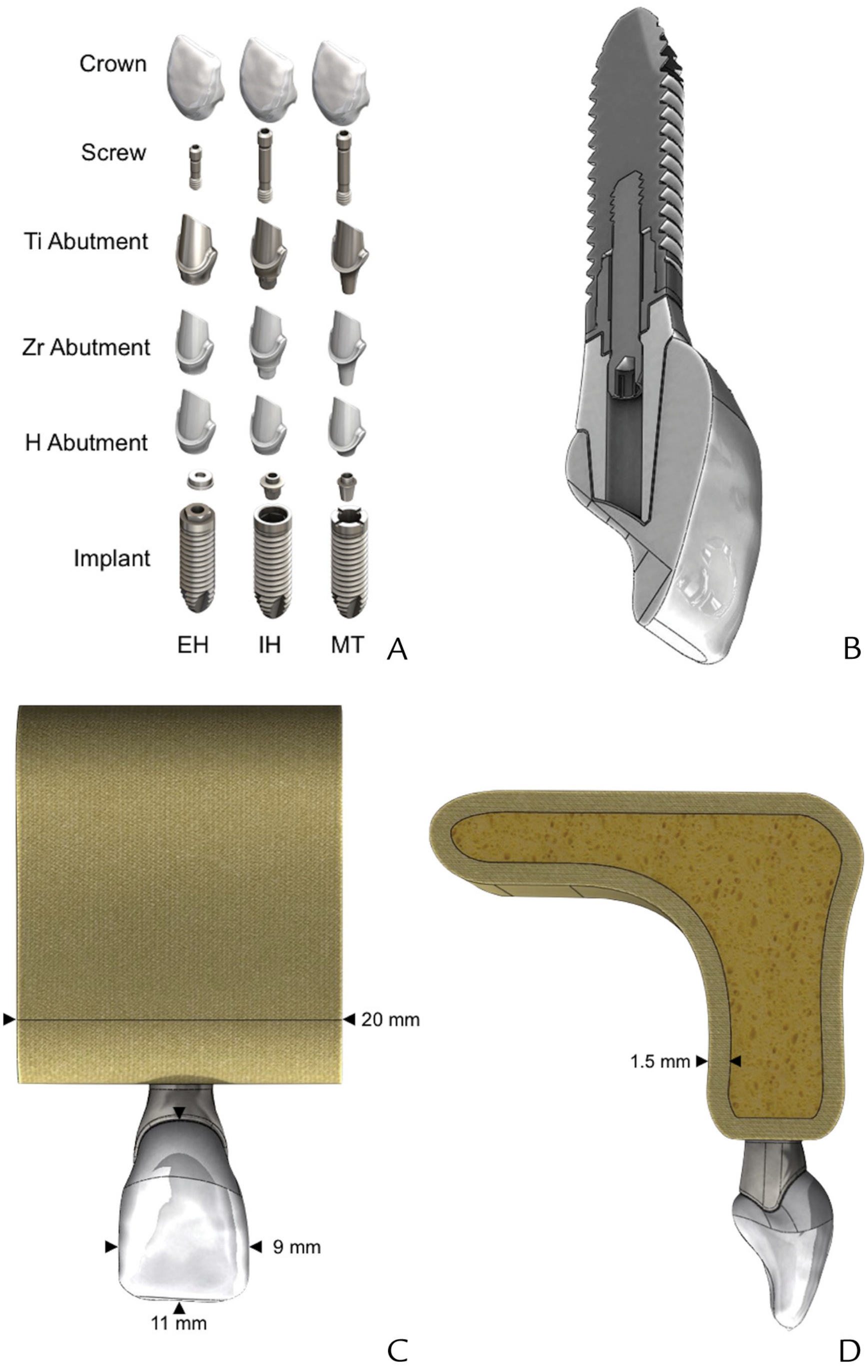
Table I. Experimental design groups

Group/ Abutment Connection	Abutment Material
External hexagon	
EHTi	Titanium
EHZr	Zirconia
EHH	Hybrid
Internal hexagon	
IHTi	Titanium
IHZr	Zirconia
IHH	Hybrid
Morse tapered	
MTTi	Titanium
MTZr	Zirconia
MTH	Hybrid

EH, external hexagon; Ti, titanium; Zr, zirconia; H, hybrid; IH, internal hexagon; MT, Morse tapered.

RESULTS

The highest σ_{vM} stress values for abutments and implants in all groups



1 Three-dimensional modeled geometries: A, Assembly parts of all groups. B, Example of internal hexagon–hybrid restoration slice visualization. C and D, Complete assembly example of external hexagon–titanium with dimensions of maxilla segment (20 mm), cortical bone (1.5 mm), and crown (9×11 mm) used for all groups.

are presented in Figure 2. To qualitatively compare all the groups, the σ_{vM} stress distribution is displayed for abutments in Figure 3 and for implant in Figure 4. The highest σ_{max} and σ_{min} for Zr and H abutments are presented in Figure 5.

Abutments

When considering the equivalent von Mises stress criterion and connection type, the highest values were found in the MT groups (315.61 MPa for the MTZr, followed by a decrease of 7% for MTH and 8% for MTTi). The stresses were concentrated on both buccal and lingual implant–abutment interface areas at the platform level (Fig. 3). The lower value (91.7 MPa) was found in the EHH group, followed by an increase of 6.4% for the IHTi group and 9.7% for the IHH group. The stress distribution for the EH groups concentrated on the cervical area of the abutment, whereas, for the IH groups, it was concentrated in the IH projection and abutment platform rest area (Fig. 3).

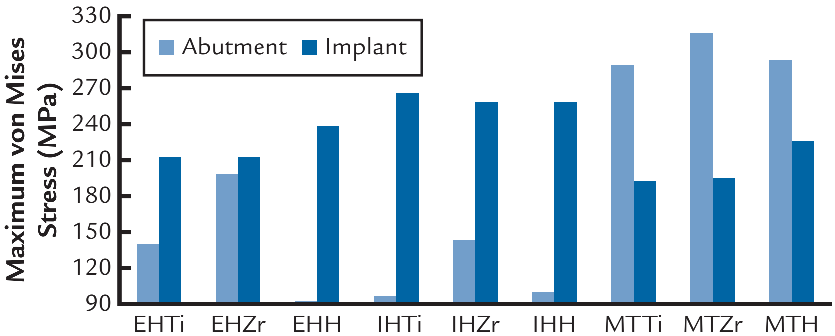
With regard to the abutment material, for Ti groups, the highest σ_{vM} occurred in the MTTi group, followed by the EHTi and IHTi groups. For the Zr groups, the highest σ_{max} and σ_{min} values in MPa were found in the MTZr group (332.3 MPa, −380.37 MPa), followed by the EHZr (107.7 MPa, −250.7 MPa) and IHZr (178.32 MPa, −162.27 MPa) groups. Among the Ti-Zr H groups, when considering only the Zr abutment body, the order was similar: MTH (194.61 MPa, −235.84 MPa), followed by EHH (85.23 MPa, −87.63 MPa) and IHH (67.31 MPa, −69.73 MPa). When considering the Ti base, the MTH group displayed the highest σ_{vM} values (293.91 MPa), followed by a reduction of 13.9% in the EHH group and 65.7% in the IHH group.

Implant

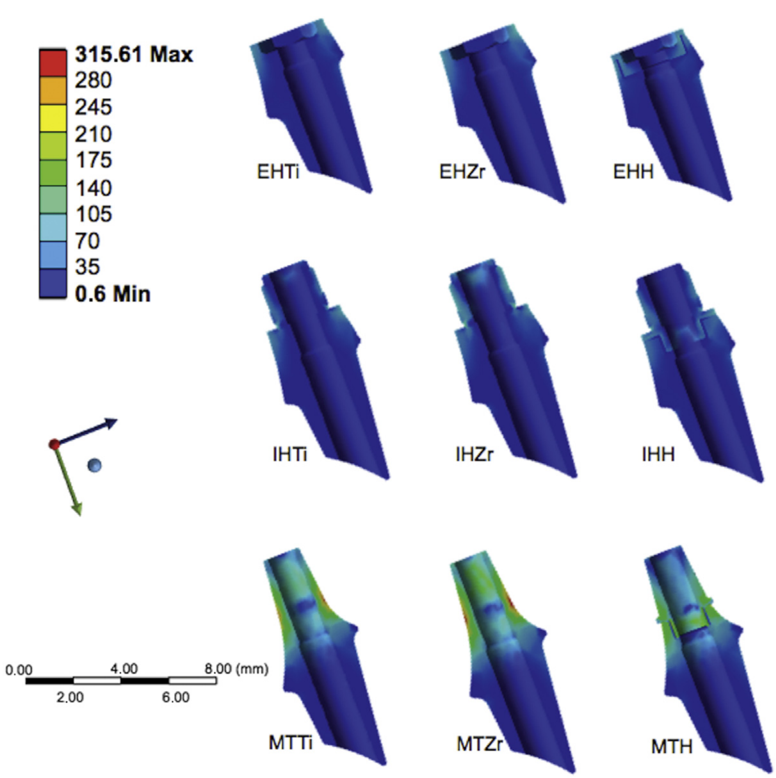
When considering the connection type, the stress patterns were almost the same and also uniformly distributed in the implants. They were concentrated in the palatal and buccal region of the implant neck and decreased closer to the implant apex, regardless the abutment material (Fig. 4). The mean (standard deviation) σ_{vM} values ranged from 204.64 ±12.13 MPa in the MT groups to 220.83 ±3.48 MPa in the EH group and 261.2 ±15.23 MPa in the IH group. For the EH groups, the greater σ_{vM} stress concentration was found in the external face of the first thread of the implant near the compact and cancellous bone interface and reached 237.98 MPa in the EHH group, with a

Table II. Materials properties adopted in the study

Material	Young Modulus (GPa)	Poisson Ratio
Resin cement[38]	18.3	0.30
Cortical bone[39]	13.6	0.26
Cancellous bone[39]	1.36	0.31
Titanium[39]	110	0.25
Zirconia[40]	205	0.22
Lithium disilicate[41]	96	0.23



2 Comparison of maximum equivalent von Mises stresses (MPa) for abutments and implants for all groups.



3 Distribution of equivalent von Mises stresses (MPa) in abutments for all groups.

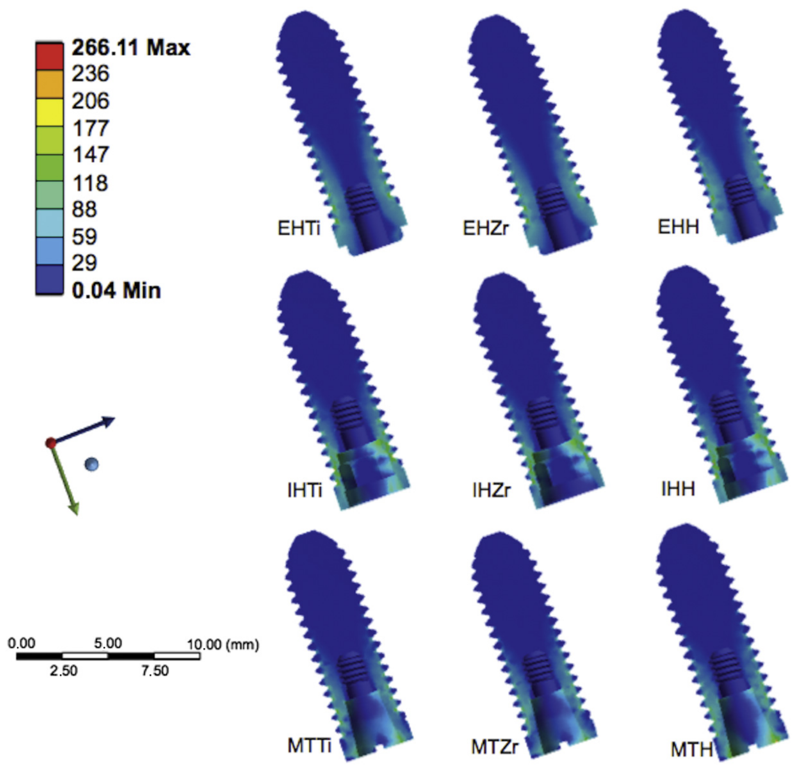
reduction of 11% for the EHTi and also the EHZr groups. For the IH groups, the maximum σ_{vM} stress was concentrated on the thinnest wall area of the implant caused by the abutment IH projection, and reached 266.11 MPa in IHTi, followed by a reduction of less than 3% for both IHZr and IHH. In the MT groups, the maximum σ_{vM} stress occurred on the internal upper abutment-implant interface at the bone level, which reached 226.08 MPa in the MTH group, followed by a reduction of 15% in the MTZr group and also in the MTTi group. Differences in the stress distribution in the implants were greater regarding the connection type than the abutment material (Fig. 4).

DISCUSSION

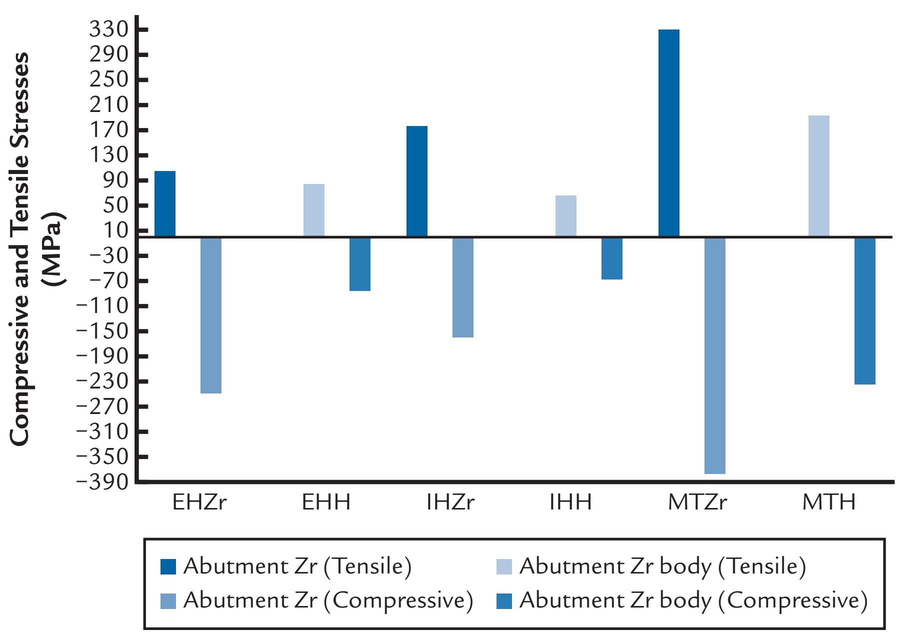
In addition to esthetic factors, the mechanical performance of ceramic abutments is a concern.[2,22] In the present study, the combination of 3 different abutment materials and 3 implant platform connections within implant-supported anterior single crowns was evaluated with FEA. Although mechanical tests have been used to analyze the fracture resistance of different abutment materials and connections on implant single crown reconstructions, they may not help understand the behavior of structure stress.[29,30]

In this study, the equivalent von Mises criterion was chosen for its ability to summarize the maximum deformation energy of a given body, even among different material properties of such rigid structures as Ti and Zr abutments. The stress concentration for σ_{vM} occurs in compressive areas, on buccal regions, on tensile areas, and on palatal regions. The stress plots were color coded according to a single stress level scale for all implants and another for all abutments, which provided a standard comparison among the groups. The maximum and minimum principal stress values were used in this study to compare the Zr and H groups among themselves because maximum and minimum principal stresses are better criteria for brittle materials such as ceramics.

The platform connection influenced the stress values and distribution more among abutments than among the implants. Thinner abutment walls are



4 Distribution of equivalent von Mises stresses (MPa) in implants for all groups.



5 Comparison of maximum (tensile) and minimum (compressive) principal stresses among zirconia and hybrid groups.

present in the MT connection design due to the horizontal mismatch in the platform switching condition. Combined with the thinner design, the brittleness of the ceramic material provided the highest σ_{max}, σ_{min}, and σ_{vM} values in the MTZr group. The IH connection provided the highest σ_{vM} values in implants. The implant walls of the IH group were thinner than those of the MT group, which may explain the results for σ_{vM} in implants. When considering all the groups, the lowest stress values in abutments were found in the EHH group, followed by the IHTi and IHH groups. The EH associated with the cementation line between the Ti base and Zr abutment body in the H group culminated in the lowest values for the EHH when compared with all the groups. Among the Ti groups, the thicker Ti abutment wall in the IHTi group provided the lowest values.

Although the abutment σ_{vM} value for the MTH group was similar to that of the MTZr group, the high σ_{vM} was due to the Ti base (293.61 MPa) and not to the Zr abutment body (194.61 MPa), which was even lower than that of the MTTi group (286.36 MPa). The presence of a Ti base in the H group significantly decreased the σ_{max} and σ_{min} stresses on the Zr abutment body in comparison with the Zr group. This fact can be attributed to the lower elastic modulus and better elastic deformation of Ti in comparison with Zr. No FEA study compares the H abutment values, although, the results obtained in the present study corroborate those of mechanical tests, which suggests better outcomes in the H groups.[15,17,18]

With regard to the evaluation of a single material abutment, previous studies reported the better mechanical performance of Ti over Zr abutments for external and internal connections.[19,34] In contrast, Firidinoğlu el al[20] reported similar results for both materials. Their findings were obtained by comparing the results of mechanical tests and FEA among internal connection Zr and Ti abutment groups. However, these results may not be compared with the present study because their FEA values were obtained only for the restoration coping and not the abutment.

The present study is the first to use FEA to compare internal and external connectioon designs associated to Ti, Zr, and H abutment materials. Recently, Çaglar et al[35] evaluated the stress distribution patterns of IH connection ceramic abutments and Ti abutments. The FEA results showed no difference among them. This might be due to the occlusal single-point loading used. The 6-step occlusal loading used in the present study generates more bending moments than a single-point loading. The excursive loading from the cingulum to incisal edge leads to a more-challenging scenario of abutment resistance, which may have increased the discrepancy between the Ti and Zr groups.

The findings of the present study should be carefully considered because of the interface conditions. To simulate the immediate implant placement and prosthetic loading in the anterior zone, the "contact" type, a nonlinear frictional contact element, was used with a 0.3 coefficient between bone and the implant.[32] The "bonded" type was used on the interfaces of the crown, abutment, screw, and implant, which were assumed to be perfectly bonded together. This condition interferes with the behavior of stress dissipation through the structures because it generates tensile stress in the palatal interface area of the abutment and implant once they are bonded together. Future studies with nonlinear contact at the Ti-Zr interface should be conducted to complement the present results.

The internal distribution of stresses acquired with FEA provides important data that, gathered with numerical values of maximum stresses (σ_{max}, σ_{min}, σ_{vM}) and fracture resistance values of mechanical tests may lead to restoration design improvements. However, the number of virtual, mechanical, and clinical studies of implant-supported ceramic restorations is still limited.[4,7,12,17,27,35-37] Therefore, further clinical, virtual, and mechanical trials with multiple combinations of abutment connections and materials are required for better abutment selection guidelines.

CONCLUSIONS

Within the limitations of this FEA, the following conclusions can be drawn:

1. The platform connection influenced the stress values and distribution on abutments more than the abutment material.
2. The stress values for implants were similar among different platform connections, but greater stress concentrations were observed in internal connections.
3. The H abutments presented similar mechanical behavior to Ti abutments and better mechanical behavior than Zr abutments.

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