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Influence of implant connection on the stress distribution in restorations performed with hybrid abutments

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ABSTRACT

Aim This study evaluated the influence of prosthetic connection type (external hexagon [EH], internal hexagon [IH] and morse taper [MT]) on the stress distribution in an implant-supported prosthesis.
Materials and methods Using modeling software, three sets were formed according to the prosthetic connection composed of ceramic crown, mesostructure, abutment, abutment screw, implant, cement layers and bone tissue. Solids were imported to the analysis software and bone model was fixed in the base. All materials were considered isotropic, linearly elastic and homogeneous. The static load (500 N, 30°) was applied in the central fossa. Stress distribution data were obtained according to Von-Mises and microstrain criteria.
Results The type of prosthetic connection influenced the stress distribution. The stresses for the IH and MT connections were concentrated on the implant and abutment; for EH at the implant, abutment screw, at the implant platform, and at the cement layer between abutment and mesostructure. There is lower influence for the crown and mesostructure, with more promising results for the MT connection. For the bone tissue, all connections showed the same strain pattern. Stress peaks of 148, 142 and 138 MPa in the implant, 134, 129 and 62 MPa in the screw, and 86, 118 and 131 MPa were observed respectively for EH, IH and MT.
Conclusions The morse taper connection showed promising performance with lower stress concentration in the abutment screw, implant platform and cement layers.

KEYWORD Dental implants; Dental implant-abutment design; Finite element analysis.

INTRODUCTION

The success of implantology is directly related to the longevity of the rehabilitation treatment (1). Once osseointegrated, the implant acts on the stomatognathic system dissipating the masticatory load (2) incident on the prosthetic crown. Rehabilitation with implants is highly versatile for a number of critical components that may be used to install the crown in the best possible way (3). Although the mechanics of the implant prosthesis system are constantly in development, the search for aesthetics by patients has also become increasingly common (4). Thus, marginal grayness, absence of papillae and presence of black spaces are aesthetic problems that are less tolerated by patients (4,5).
In order to alleviate aesthetic problems, purely ceramic abutments were used as an option for the metal of conventional abutments (6,7). However, the ceramic/titanium interface does not achieve the same seating precision compared to titanium/titanium interface (8). The higher vertical misfit combined with the different hardness between abutment and implant limits the use of purely ceramic abutments in single rehabilitations (6-9), especially when external connections are used (10).
Hybrid abutments have emerged in order to improve the aesthetics without the use of a purely metallic abutment. A hybrid abutment consists of a mesostructure cemented onto a metallic prosthetic connection (titanium base) (11-14,15). With the development of CAD/CAM (Computer Aided Design/Computer Aided Manufacturing) technology, ceramic blocks can be machined in different ways, including for the purpose of making individualized mesostructures according to the emergency profile of each patient. The mesostructures are cemented in extra-oral medium onto titanium bases with standard height and diameter, available for several prosthetic connections (11-14).
In this way, pink aesthetics can be improved due to higher volume of ceramic material. However, there are few reports about the mechanical effect of the use of

hybrid abutment in the implant, and there is no data about different prosthetic connections. Therefore, the purpose of this study was to analyze the stresses generated in single crown rehabilitations using hybrid abutments of different prosthetic connections by the finite element method. The alternative hypothesis was that there would be no difference in the stress generated according to the prosthetic connection used.

MATERIALS AND METHODS

Finite Element Analysis modeling

Three three-dimensional (3D) models were made using CAD software (Rhinoceros 5.0, SR8, McNeel North America, Seattle, WA, USA). Each model had all the individual structures present in a unitary rehabilitation with a hybrid abutment (15), including: monolithic ceramic crown, ceramic mesostructure, titanium base, screw, resin cement, implant and bone. All three groups were divided according to the prosthetic connection modeling of the implant: external hexagon (EH), internal hexagon (IH) and morse-taper (MT). For cement layers, the resin cement thickness considered was 0.3 mm (16). The titanium base was standardized for all prosthetic connections (NP model, 4.5 x 5 mm), as well as the size of the implants (3.75 x 11 mm) in following the manufacturer dimensions (Conexão Sistemas de Prótese, Arujá, SP, Brazil). The 3D modeling was arranged in Figure 1 according to the clinical sequence of making a unitary restoration using a hybrid abutment. Solids were subsequently imported to analysis software (ANSYS 17.2, ANSYS Inc., Houston, TX, USA) in STEP format.

Boundary condition and mesh generation

The bone model was fixed in all directions. The static load (500N, 30°) was applied in the central fossa according to ISO 14801:2012 (Fig. 2). The subdivision of the complex geometries into a finite number of elements was performed according to the mesh convergence test of 10% (17). Thus, mesh was generated with quadratic tetrahedral elements containing 518,170 nodes and 280,320 elements for the IH group; 507,242 nodes and 272,186 elements for the EH group and, 519,864 nodes and 288,862 elements for the MT group. All materials were considered isotropic, linearly elastic and homogeneous. The restorative material used in the ceramic crown was a lithium disilicate, and yttria-tetragonal zirconia polycrystal (YTZP) was used for the mesostructure (15). Material mechanical properties were obtained from literature (Table 1) (18-21). Results of stress distribution according to Von Mises criterion for the set, titanium base, screw, cement layers, implant platform and mesostructure are shown through color graphs with their respective scale in megapascals (MPa). For the bone tissue, the results were analyzed according to the microstrain criterion. The structures were analyzed

Structure/material	Elastic modulus (in Gigapascal)	Poisson ratio
Zirconia (18)	220	0.3
Lithium dissilicate (19)	63.9	0.22
Cortical bone (20)	13.7	0.3
Medullary bone (20)	1.37	0.3
Resinous cement (21)	7.5	0.25

TABLE 1 Mechanical properties of the materials and structures used.

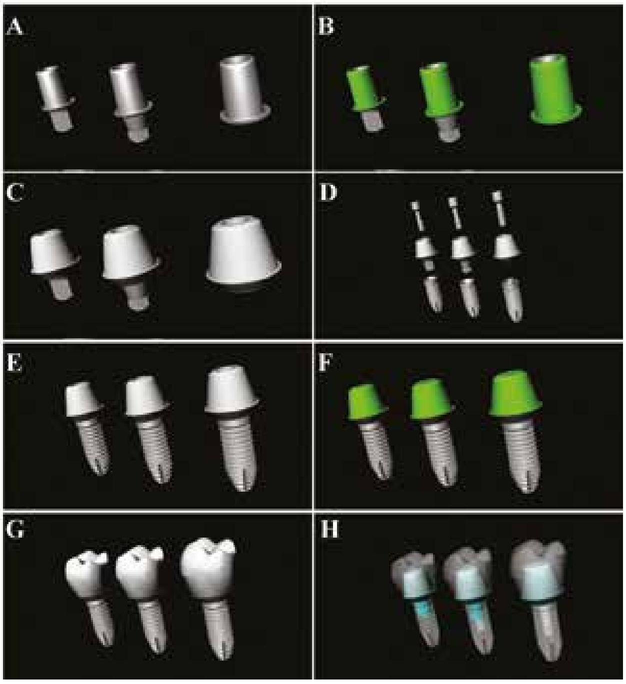

FIG. 1 Schematic illustration of 3D modeling following the clinical sequence of making a unitary restoration using a hybrid abutment. A) Titanium base. B) Cement layer between titanium base and ceramic mesostructure. C) Hybrid abutment: Ceramic mesostructure cemented on the titanium base. D) Prosthetic screw, hybrid abutment and implant. E) Hybrid abutment screwed to the implant. F) Cement layer between hybrid abutment and ceramic crown. G) Ceramic crown screwed to the implant. H) Final 3D model containing all modelled structures. From the left to the right, respectively, IH, MT and EH.

FIG. 2 Final 3D model (ISO 14801) for fixing and applying load (500 N, 30°).

Structure	External Hexagon	Internal Hexagon	Morse Taper
Titanium base	86	118	131
Screw	134	129	62
Cement between abutment and mesostructure	19.5	17.2	17
Cement between mesostructure and crown	10	11	12
Implant	148	142	138
Mesostructure	49	51	43

TABLE 2 Stress peaks (in Megapascal) observed in each evaluated structure by Von-Mises criterion.

separately to facilitate visualization of the stress map, so that each one of them could be assumed as failure criterion and results could be compared between the groups.

RESULTS

In Figure 3 (first line) it is possible to observe that the mechanical behavior of the set presents similarity between the groups. In the second line (Fig. 3), the generated von Mises stress in the prosthetic abutments shows that the groups with internal connections present more stress concentration in this structure than the EH connection; but this situation is reversed when the prosthetic screw is analyzed (3rd line), and the MT connection presents the lowest stress concentration in the screw. The sagittal view of the cement layer between titanium base and mesostructure subsequently reveals an important stress concentration in the EH group, whereas IH and MT are similar and have lower stresses (4th line). Little difference was noticed for the cement layer between crown and mesostructure (5th line). The implant platform shows more damaging stress for the EH connection, followed by the IH and MT groups, respectively (6th line). The ceramic mesostructures showed similar mechanical behavior among the tested groups, with MT connection being less harmful than the other groups (7th line). The stress peaks (MPa) observed in each evaluated structure are shown in Table 2. All groups in the cervical region exhibited maximum values of 500 microstrain on the bone, with similarity in the areas affected among them (8th line).

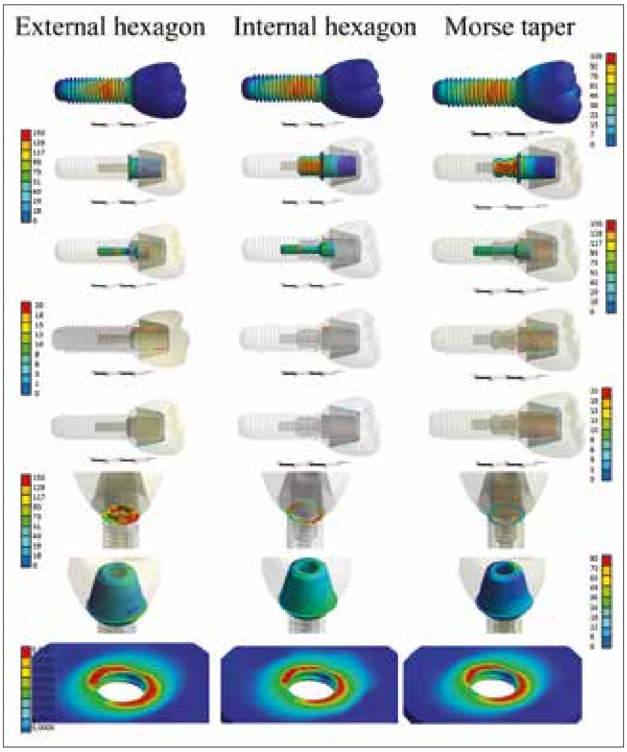

FIG. 3 Color graph of stress distribution according to Von-Mises criterion for the set, abutment, abutment screw, cement layers, implant platform and mesostructure (MPa), respectively, and microstrain results for the bone tissue.

DISCUSSION

This study compared hybrid abutments used in prosthetic systems over implants with three different prosthetic connections. The hypothesis of this study was rejected since the biomechanical behavior of the system was influenced by the type of connection. The prosthetic connection is a heavily researched object of study in the scientific literature on dental implants (22-29). This is because the union between abutment and implant is directly related to the success and longevity of the treatment (30). The prosthetic connection may influence bone remodeling (30), maintenance of the screw torque (28), intensity of deleterious stresses (23,24), aesthetics (5), fracture of components (31), crown misfit (31), amount of soft tissue (5), presence of biofilm and bacterial infiltrate (25), wear of the implant platform (9) and even the success rate of osseointegrated implants (1). Different implant and prosthesis systems are still being introduced to reduce the incidence of the mechanical and biological problems present in the oral environment. In addition, some authors have concluded that there is no consensus on the best prosthetic connection for all aspect (22-25,28), as it is not possible to standardize a single form of implant prosthesis due to the particular differences of each clinical case.

The restorative modality simulated in the present study aims to maintain the union between abutment and implant in metal, however most of the hybrid abutment volume is composed of ceramic (15). This mesostructure is cemented on the titanium base and a crown is cemented over it; in this case, a lithium disilicate crown. The titanium base is very similar to a traditional metallic abutment for cemented prosthesis. Its main feature is to be thin enough so that the metallic volume of the abutment is smaller but it is still able to withstand masticatory forces (31), despite being less resistant to compression than solid titanium abutments (31). The titanium base is not yet suitable for intra-oral cementation as the settlement platform is thin and close to the implant, and it would be difficult to remove the resin cement excess from that region (15,31).

When selecting a hybrid abutment, the clinician will be recommending a treatment that has two cement layers: the first one is responsible for joining the titanium base and the mesostructure; and the second one is responsible for joining the mesostructure to the prosthetic crown. Both cement layers of the present study were standardized with uniform thickness and absence of defects (16). In this ideal situation it is possible to observe that the choice of the prosthetic connection has low interference in the cement layer between crown and mesostructure. However, when using an implant with EH, it is possible to perceive that the cement between the hybrid abutment and the titanium base is more damaged than when another prosthetic connection is used. The results suggest that the group with EH probably would debond more easily after masticatory function. This is justified because there is greater stress concentration in the implant platform, so that the higher stress region for IH as well as for MT is inside the implant, far from the cement layer between the titanium base and mesostructure.

The results also demonstrate that EH group shows more stress in the abutment screw, in the region of the outermost thread, followed by the group with IH and MT implants, respectively. These results are supported by other studies that have evaluated the influence of the prosthetic connection on implant-supported crowns and demonstrated superiority for MT group in attenuating the failures generated in the abutment screw (24,26). This orientation of the implant's inner walls associated with a less abrupt change in geometry makes this system mechanically superior to the abutment screw protection. This same mechanical behavior is reflected in the implant platform, because the group with EH ends up further damaging this region, followed by the group with IH, and finally the group with MT. The stress in the platform is probably more homogeneous as the masticatory force is directed towards the center of the implant, reflecting a better prognosis for the MT connection (23).

The prosthetic crown, the cement between the crown and mesostructure, and the mesostructure itself had less influence of the connection type. This is expected since all these structures were identically modeled for all groups and had the same material properties. Moreover, these structures are distant from the prosthetic connection region, which causes the generated stress to be similar between the evaluated groups. Even so, there is a difference in these regions, which would probably be intensified with the use of crowns and mesostructures made of different restorative materials, application of occlusal overloads or cements with high polymerization shrinkage.

The analyzed bone tissue was the cortical bone of the peri-implant region (16,29). A similarity in the way the microstrains dissipated in this specific region was observed in all groups. Microstrain peaks did not exceed 500 microstrain (μm/μm), being defined as physiological values of bone maintenance (33). These results make it possible to visualize that the EH group presents a larger red area than the other groups. The use of implants 3mm distant from the bone may have influenced these results, as it is already demonstrated that significant changes in bone microstrain are observed when implants are exposed (16). However, the effect of exposed threads (3 mm) was present for all groups, following the ISO 14801:2012, representing the fulcrum region.

This study was carried out using a theoretical computational methodology widely used in implantology (16,24,26). The results should be carefully checked, since (like a laboratory study) there are limitations in the Finite Element Analysis method (29), such as: simulation of isotropic materials with no defects, ideal contact between bodies and perfect cementation, absence of maladaptation and tolerance factor between prosthetic pieces, PH variations and temperatures present in the oral medium. Therefore, the results herein are valid to demonstrate that some differences were verified in this ideal situation, in which oral medium can be intensified depending on the prosthetic connection used to rehabilitate a tooth using a hybrid abutment.

A few studies are available regarding the failure type of hybrid abutments (11-14). A 100% survival rate was observed after chewing simulation (1,200,000 cycles) of monolithic crowns in lithium disilicate cemented on zirconia hybrid abutments (13,14). Restorations submitted to a quasi-static loading at 30° degrees to the implant axis presented a permanent plastic deformation at the screw and internal connection of the titanium base without ceramic fracture (12,14). The posterior crown also survived the chewing simulation, but presented a different failure mode under a static axial load (13). Only cohesive fracture within the monolithic crown was observed, and none of the hybrid abutments fractured upon completion of the monotonic test. Also, when evaluating the zirconia monolithic crown cemented onto a zirconia hybrid abutment failures occurred when a 30° load is applied due to bending the implant neck (11). The posterior crown herein received a static load (500N, 30°) in the central fossa. Considering those previous studies and our modeling conditions, EH would favor plastic deformation at the screw and connection, IH would favor plastic deformation at the screw, connection and titanium base, while MT would only present plastic deformation at the titanium base. Thus, MT implant connection showed less concentrated stress risk areas. Therefore, laboratory studies are necessary to prove MT's superiority.

CONCLUSION

Hybrid abutments were created with the purpose of associating the connection of the metal abutment and the aesthetics of the ceramic abutment.

Regarding the stress distribution, the hybrid abutment is more indicated for the morse taper implant.

The mechanical response of a cemented crown on hybrid abutment can be altered depending on the prosthetic connection.

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REFERENCES

1. Tey VHS, Phillips R, Tan K. Five-year retrospective study on success, survival and incidence of complications of single crowns supported by dental implants. Clin Oral Implants Res 2017; 28:620-625.
2. Adell R, Lekholm U, Rockler B, Brånemark PI. A 15-year study of osseointegrated implants in the treatment of the edentulous jaw. Int. J. Oral. Surg 1981; 10:387-416.
3. Patil R, Gresnigt MMM, Mahesh K, Dilbaghi A, Cune MS. Esthetic Evaluation of Anterior Single-Tooth Implants with Different Abutment Designs-Patients' Satisfaction Compared to Dentists' Observations. J Prosthodont 2017; 26:395-398.
4. Bennani V, Ibrahim H, Al-Harthi L, Lyons KM. The periodontal restorative interface: esthetic considerations. Periodontol 2000 2017; 74:74-101.
5. Poskevicius L, Sidlauskas A, Galindo-Moreno P, Juodzbalys G. Dimensional soft tissue changes following soft tissue grafting in conjunction with implant placement or around present dental implants: a systematic review. Clin Oral Implants Res 2017; 28:1-8.
6. Willmanii G. Frettitig of modular iinplaiit systems. Riomed Tech (Berlin) 1993; 3:48-52.
7. Glauser R, Sailer I, Wohlwend A, Studer S, Schibli M, Schärer P. Experimental zirconia abutments for implant-supported single-tooth restorations in esthetically demanding regions: 4-year results of a prospective clinical study. Int J Prosthodont 2004; 17:285-290.
8. Brodbeck U. The ZiReal Post: A new ceramic implant abutment. J Esthet Restor Dent 2003;15:10-23.
9. Bidra AS, Rungruanganunt P. Clinical outcomes of implant abutments in the anterior region: a systematic review. J Esthet Restor. Dent 2013; 25:159-176.
10. Gehrke P, Johannson D, Fischer C, Stawarczyk B, Beuer F. In vitro fatigue and fracture resistance of one- and two-piece CAD/CAM zirconia implant abutments. Int J Oral Maxillofac Implants 2015; 30:546-554.
11. Stimmelmayr M, Heiß P, Erdelt K, Schweiger J, Beuer F. Fracture resistance of different implant abutments supporting all-ceramic single crowns after aging. Int J Comput Dent 2017; 20:53-64.
12. Elsayed A, Wille S, Al-Akhali M, Kern M. Comparison of fracture strength and failure mode of different ceramic implant abutments. J Prosthet Dent 2017; 117:499-506.
13. Elshiyab SH, Nawafleh N, Öchsner A, George R. Fracture resistance of implant-supported monolithic crowns cemented to zirconia hybrid-abutments: zirconia-based crowns vs. lithium disilicate crowns. J Adv Prosthodont 2018; 10:65-72.
14. Elsayed A, Wille S, Al-Akhali M, Kern M. Effect of fatigue loading on the fracture strength and failure mode of lithium disilicate and zirconia implant abutments. Clin Oral Implants Res 2018; 29:20-27.
15. Tribst JPM, Piva AMODAL, Borges ALS, Bottino MA. Influence of crown and hybrid abutment ceramic materials on the stress distribution of implant-supported prosthesis. Rev Odontol UNESP 2018; 47:149-54.
16. Tribst JPM, Dal Piva AMO, Shibli JA, Borges ALS, Tango RN. Influence of implantoplasty on stress distribution of exposed implants at different bone insertion levels. Braz Oral Res 2017; 31:e96.
17. Tribst JPM, Morais DC, Alonso AA, Dal Piva AMO, Borges ALS. Comparative three-dimensional finite element analysis of implant-supported fixed complete arch mandibular prostheses in two materials. J Indian Prosthodont Soc 2017; 17:255-260.
18. Piconi C, Maccauro G. Zirconia as a ceramic biomaterial. Biomaterials 1999;20:1-25.
19. Ramos N de C, Campos TM, Paz IS, Machado JP, Bottino MA, Cesar PF et al. Microstructure characterization and SCG of newly engineered dental ceramics. Dent Mater 2016; 32:870-878.
20. Monteiro JB, Dal Piva AMO, Tribst JPM, Borges ALS, Tango RN. The effect of resection angle on stress distribution after root-end surgery. Iran Endod J 2018; 13:188-194.
21. Jongsma LA, de Jager N, Kleverlaan CJ, Pallav P, Feilzer AJ. Shear bond strength of three dual-cured resin cements to dentin analyzed by finite element analysis. Dent Mater 2012;28:1080-1088.
22. Coelho PG, Sudack P, Suzuki M, Kurtz KS, Romanos GE, Silva NR. In vitro evaluation of the implant abutment connection sealing capability of different implant systems. J Oral Rehabil 2008; 35:917-924.
23. Tonella BP, Pellizzer EP, Ferraço R, Falcón-Antenucci RM, Carvalho PS, Goiato MC. Photoelastic analysis of cemented or screwed implant-supported prostheses with different prosthetic connections. J Oral Implantol 2011; 37:401-410.
24. Dayrell AC, Noritomi PY, Takahashi JM, Consani RL, Mesquita MF, dos Santos MB. Biomechanical analysis of implant-supported prostheses with different implant-abutment connections. Int J Prosthodont 2015; 28:621-623.
25. Romanos GE, Biltucci MT, Kokaras A, Paster BJ. Bacterial Composition at the implant-abutment connection under loading in vivo. Clin Implant Dent Relat Res 2016; 18:138-145.
26. de Andrade CL, Carvalho MA, Del Bel Cury AA, Sotto-Maior BS. Biomechanical Effect of prosthetic connection and implant body shape in low-quality bone of maxillary posterior single implant-supported restorations. Int J Oral Maxillofac Implants 2016; 31:e92-e97.
27. Pessoa RS, Sousa RM, Pereira LM, Neves FD, Bezerra FJ, Jaecques SV et al. Bone remodeling around implants with eh and morse-taper connections: a

randomized, controlled, split-mouth, clinical trial. Clin Implant Dent. Relat Res 2017; 19:97-110.

28. Saleh Saber F, Abolfazli N, Jannatii Ataei S, Taghizade Motlagh M, Gharekhani V. The effect of repeated torque tightening on total lengths of implant abutments in different internal implant-abutment connections. J Dent Res Dent Clin Dent Prospects 2017; 11:110-116.
29. Datte CE, Tribst JPM, Dal Piva AMO, Nishioka RS, Bottino MA, Evangelhista ADM et al. Influence of different restorative materials on the stress distribution in dental implants. J Clin Exp Dent 2018; 10:e439-e444.
30. Ricomini Filho AP, Fernandes FSDF, Straioto FG, Silva WJD, Del Bel Cury AA. Preload loss and bacterial penetration on different implant-abutment connection systems. Braz Dent J 2010; 21:123-129.
31. Sanivarapu S, Moogla S, Kuntcham RS, Kolaparthy LK. Implant fractures: Rare but not exceptional. J Indian Soc Periodontol 2016; 20:6-11.
32. Rosentritt M, Raab P, Hahnel S, Stöckle M, Preis V. In vitro performance of CAD/CAM-fabricated implant-supported temporary crowns. Clin Oral Investig 2017; 21:2581-2587.
33. Frost HM. Wolff's Law and bone's structural adaptations to mechanical usage: an overview for clinicians. Angle Orthod 1994; 64:175-188.