Influence of Metal and Ceramic Abutments on the Stress Distribution Around Narrow Implants: A Photoelastic Stress Analysis

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Purpose: *This study aimed to compare, through photoelastic analysis, the distribution of stresses around narrow implants with external hexagon (EH) and Morse taper (MT) connections, when single crowns made with metal and ceramic abutments were used.*

Materials and Methods: *Six photoelastic models were prepared, simulating the use of narrow EH and MT implants replacing a lateral incisor. These 2 groups received 3 different abutments: prefabricated metal abutments, customized metal abutments, and customized zirconia abutments. All crowns were identical and made with a leucite reinforced glass-ceramic. Vertical loads of 0 to 100 N were applied on the palatal surface of the crowns, and the photoelastic stress fringes developed in each model were captured in a high-definition video, and digital photographs were taken at 100 N.*

Results: *The abutment type and material influenced the stress distribution patterns around narrow implants with EH and MT connections. Stresses were generated mainly around the apical and lingual regions of the implants.*

Conclusions: *For both connections, the prefabricated metal abutments presented better stress distribution around the implants when compared to customized metal and zirconia abutments because low stress levels were developed in smaller areas around the implants. (Implant Dent 2016;25:1–5)*

Key Words: photoelastic stress analysis, dental implants, abutment material

Single restorations and fixed implant-supported dental prosthesis have become a well-accepted treatment option for the rehabilitation of partially or completely edentulous patients. The literature has reported excellent long-term survival rates for different types of implant-supported prostheses, especially in cases of rehabilitation of single tooth losses.[1,2]

The replacement of single teeth in the anterior region presents the dentist with a most challenging situation. In these cases, the placement of osseointegrated implants for prosthetic rehabilitation is a feasible alternative and has been successfully described in the literature.[3,4] Especially in the case of absence of maxillary lateral incisors, due to the small vestibular-palatine bone thickness and reduced interproximal space, narrow implants with smaller platforms are frequently used.[5,6] This type of implant with a narrower prosthetic platform avoids loss of space in the papillae during the prosthetic stage, in addition to maintaining a slightly thicker cortical bone, both in the vestibular and palatine regions, which may help with the stability of the adjacent soft tissues.[5]

The use of metal abutments has been considered an essential condition for the longevity of implant-supported prostheses.[7] However, particularly in anterior rehabilitations, the esthetic factor has become critically important for their clinical success. One of the main problems related to the use of metal abutments is their darkened color, which may cause the appearance of discoloration and/or grayish aspect of the periimplant mucosa when they are used. Thus, despite being considered

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very stable and predictable, there maybe limitations on the indications of metal abutments in areas involving esthetics.[8]

As an alternative to metal abutments, ceramic components mainly fabricated of yttrium tetragonal zirconia polycrystal (Y-TZP) have gained popularity over the last few years. The zirconia abutments have advantages in comparison with the metal type, among them, better esthetics and lower potential of discoloring the periimplant mucosa,[9] and less bacterial adhesion to the surface.[10] In addition, zirconia presents excellent biocompatibility[11,12] and capacity for osseointegration.[13,14] Regarding the mechanical properties, zirconia has high mechanical strength and elevated fracture resistance. However, as disadvantages, ceramics are fragile materials that do not bear high tensile stresses.[15]

The biomechanical behavior between zirconia abutments and different platform interfaces is a concern and has been previously evaluated.[16] However, despite the growing use of prefabricated or personalized ceramic abutments, there are still doubts regarding the stress distribution around implants when components of different materials and designs are used. Therefore, the aim of the present study was to compare, by means of a photoelastic analysis, the stress distribution around narrow implants with external hexagon (EH) and Morse taper (MT) connection, when single dental prostheses made with metal and ceramic abutments (prefabricated or customized) were used.

Materials and Methods

Six narrow implants were selected, being 3 with MT connections (3.6 × 11.5 mm, Attract; Systhex Sistema de Implantes, Curitiba, PR, Brazil) and 3 with EH connections (3.3 × 11.5 mm, Fit-hex; Systhex Sistema de Implantes). The selected abutments were 2 standard metal prefabricated abutments and 2 UCLAs, used to produce customized metal abutments. In addition to these, 2 customized zirconia abutments were fabricated using a CAD/CAM system, with the same shape and dimensions of the customized metal abutments. Six maxillary lateral incisors standardized ceramic crowns, made of IPS Empress (IvoclarVivadent, Schaan, Liechtenstein) by the heat-pressing technique, were cemented on the abutments with a flowable resin composite (Natural Flow, shade A3; DFL, Rio de Janeiro, RJ, Brazil) and each surface was light-cured for 40 seconds with an LED curing unit with an irradiance of 1000 mW/cm^2 (Translux Power Blue; Heraeus Kulzer GmbH, Hanau, Germany).

Photoelastic models of 10 × 40 × 60 mm were constructed with a rigid epoxy resin (Resina Rígida G IV; Polipox, São Paulo, SP, Brazil) and prepared according to the manufacturer's instructions. During the polymerization period of the epoxy resin, the molds were maintained at 20 psi pressure for 10 hours.

The photoelastic models were fabricated inserting the implants at 90 degrees in relation to the horizontal plane. The EH implants were placed with its platform at the epoxy resin surface, simulating the bone level, and the MT were placed simulating a 2-mm infraosseous implant.

Before the tests, all models were evaluated in the polariscope (Optovac, Osasco, SP, Brazil) to verify the presence of residual stress. For the tests, the models were placed on a support and taken to the polariscope coupled to a universal testing machine (DL2000; Emic, São José dos Pinhais, PR, Brazil). Axial loads from 0 to 100 N were applied in the region of the cingulum of the lateral incisor crowns. The point of load application had a rectangular format (4 mm × 1.5 mm), with a total area of 6 mm^2 (approximate stress attained was 16.7 MPa). The crosshead speed was 1 mm/s. During load application, the images were captured in a high-definition video, and digital photographs were taken at 100 N.

To capture the videos and photographic images, high-definition photograph/video cameras were used (D7000; Nikon, Tokyo, Japan; Micro Nikkor 105 mm lens). For standardization of the image capturing procedure, a camera with manual setting of focus, aperture (f/9), speed (1/60), and ISO (400) was used. The balance of whites was set to the automatic mode. Furthermore, during acquisition of the videos, the camera was mounted on a tripod at a fixed focal distance.

The photoelastic stress fringes developed in each model were visually monitored on the recorded videos and on the digital photographs (taken at 100 N). The stress intensity (number of fringes), stress concentration (closeness of fringes), and their locations were subjectively compared. To describe the stress data, low stress was considered when 1 fringe or less was observed, moderate stress when between 1 and 3 fringes were seen, and high stress when more than 3 fringes were identified.

Results

Figure 1 shows the isochromatic fringe patterns generated around the narrow implants for each model: EH and MT connections, with prefabricated metal abutments, customized metal abutments, and customized zirconia abutments. For all models, stresses were generated mainly around the apical and lingual regions of the implants. Compressive stresses were also observed around the body of all implants.

For the EH implants, it can be observed that the prefabricated metal abutment showed better results in terms of stress distribution because low stress was developed in a smaller area around the implant when compared to customized metal and zirconia abutments. When the customized metal abutment was used, a favorable stress distribution pattern was also identified. In this case, when compared to prefabricated metal abutment, stresses of similar low intensity were seen in a larger area, located specially at the vestibular area of the implant. The customized zirconia abutment presented moderate stress developed in a larger area around the body of the implant, being considered, among these 3 situations, the most unfavorable stress distribution pattern.

For the MT implants, once again, the prefabricated metal abutment showed better stress distribution characteristics because low stress was concentrated in a small area around the body of the implant. The customized zirconia abutment showed stresses of similar intensity to prefabricated metal

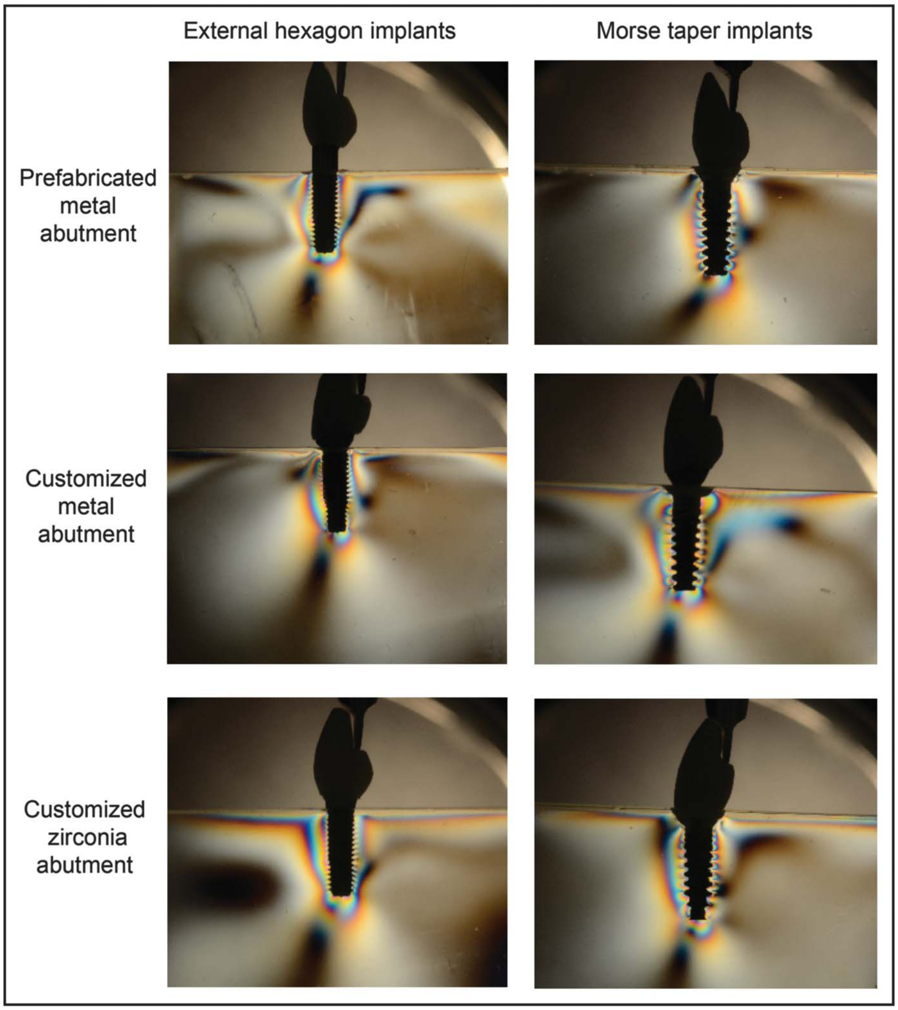

Fig. 1. Isochromatic fringe patterns generated around the dental implants for EH and MT connection implants, with prefabricated metal abutments, customized metal, and zirconia abutments. For EH, prefabricated metal abutment showed low stress developed in a smaller area around the implant. Customized metal abutment showed stresses of similar low intensity to prefabricated metal abutments but located in a larger area, mainly at the vestibular area of the implant. The customized zirconia abutment presented moderate stress developed in a larger area the implant. For MT, prefabricated metal abutment presented low stress concentrated in a small area around the implant. The customized zirconia abutment showed stresses of similar intensity to prefabricated metal abutment but less concentrated at the cervical region when compared to the customized metal abutment.

abutment developed around the body of the implant and less concentrated at the cervical region when compared to the customized metal abutment. Thus, the customized metal abutment presented the most unfavorable stress distribution pattern, with moderate stress located in a larger area, especially at the cervical region of the implant.

DISCUSSION

The null hypothesis of the present study, which was to verify whether the distribution of stresses was similar around narrow implants with EH and MT connections when single ceramic crowns fabricated over prefabricated and customized metal and ceramic abutments were used, was rejected. Different stress distribution patterns were observed around the implants, depending on the implant connection and abutment placed on them.

The distribution of stresses around osseointegrated implants and how the loads are dissipated on the bone must be well understood, especially because the lack of periodontal ligament may impair the stress distribution. This can lead to bone loss if high stresses are concentrated on the bone-implant interface.[17]

In the present study, narrow implants were used because the literature reports high success rates and satisfactory functional-esthetic results when narrow implants (3.3 mm in diameter) are used, in cases of maxillary lateral incisor agenesis.[6] The use of these narrow implants also have the goals of maintaining space for accommodating the papillae,[5] and maximization of prosthetic results. Besides, few studies investigated the stress distribution developed around narrow implants, either replacing anterior or posterior teeth.[18,19] In this way, this study can contribute to a better understanding of the transmitted stresses and the biomechanical behavior of the surrounding bone of such implants.

It is important to emphasize that there is no consensus about the preferred use of either prefabricated or customized abutments, and the studies have not yet reached a definition about which is the most interesting model from the standpoint of stress distribution around implants.[20] Furthermore, the use of prosthetic structures associated with zirconia abutments in esthetic areas raises new questions about the capacity of masticatory load distribution on the implants and adjacent bone[2] as well as the mechanical resistance of these esthetic abutments.[8,21] In this study, the use of customized metal and zirconia abutments poses interesting prosthetic considerations. Cast metal abutments can be easily waxed to the desired final form and can replicate the emergence profile established by the provisional restoration.[9] Prefabricated ceramic abutments are more difficult to use in some clinical situations. In addition, preparation of the ceramic abutment may induce crack propagation and lead to catastrophic failure in the long term.[22] However, the use of customized zirconia abutments processed by the CAD/CAM technology may provide new options for implant-supported restorations, especially in cases when there is narrow interdental space, esthetic/occlusal requirements or when the profile must be optimized to the anatomical dimensions.

Another important aspect to discuss is the elastic modulus of the materials used as abutments. A material with smaller elastic modulus presents smaller flexural resistance, whereas substructures made with rigid metal alloys undergo smaller deformation because they are less susceptible to fatigue. Therefore, the use of alloys with high elastic modulus, such as cobalt-chromium, for implant-supported prostheses may be recommended.[23] Prefabricated metal abutments are made of the same alloy as the implant, favoring the stress distribution. Customized abutments were made of materials with higher values of elastic modulus, cobalt-chromium alloy, and zirconia (with Young modulus of approximately 200 GPa).[24,25] Therefore, the transmission of stresses to the implant and surrounding bone maybe more critical. Thus, in the present study, the metal prefabricated abutments were chosen as controls.

For both EH and MT implants, different stress distribution patterns were observed according to the abutment type and material. For the EH, it was possible to see a more homogeneous stress distribution pattern when metal abutments were used, which were relatively similar between them, in comparison with the customized zirconia abutment. As for the MT implants, the prefabricated metal abutments and customized zirconia abutments presented more favorable results, in comparison to the customized metal abutments.

In the present study, it was not possible to compare the results of EH and MT implants. This was due to the fact that they were installed in different positions, while the EH implants were placed at the bone level, the MT were placed simulating a 2-mm infraosseous implant. They also have slightly different design, thread distribution, and diameter. In general, for single-unit implants, internal connection presents more favorable stress distribution patterns than do external connection systems.[26,27]

Regarding the load applied, it is known that typical human occlusal forces during mastication can vary greatly, influenced by a number of factors, such as craniofacial morphology, age, gender, temporomandibular disorders, pain, and dental conditions.[28] And although some may consider bite forces in the lateral incisor area of approximately 89 N,[29] others may describe a range of approximately 90 N for females to 140 N for males.[30]

Finally, it is important to point out that this study has some limitations, such as the use of one model for each condition and the fact that the models are unable to simulate all the conditions found during clinical practice. Also, the structure and physical properties of photoelastic resins cannot simulate the complex nature of the bone and its tissues. Therefore, further studies are necessary for better determine the stress distribution around implants, in addition to simulating other conditions routinely found in the dental practice. Despite these limitations, continuing studies toward the improvement of the photoelastic resin physical properties to better simulate the natural bone structure and the replication of samples with the intention to achieve data power for statistical analysis are strategies for ongoing works.

CONCLUSIONS

It can be concluded that the abutment type (prefabricated or customized) and material (metal or zirconia) influenced the stress distribution patterns around narrow implants with EH and MT connections. For both connections, the prefabricated metal abutments presented better stress distribution around the narrow implants when compared to customized metal and zirconia abutments because low stress levels were developed in smaller areas around the implants.

DISCLOSURE

The authors claim to have no financial interest, either directly or indirectly, in the products or information listed in the article.

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