A Finite Element Analysis of Two Different Dental Implants: Stress Distribution in the Prosthesis, Abutment, Implant, and Supporting Bone

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This study evaluates the influence of 2 commercially available dental implant systems on stress distribution in the prosthesis, abutment, implant, and supporting alveolar bone under simulated occlusal forces, employing a finite element analysis. The implants and abutments evaluated consisted of a stepped cylinder implant connected to a screw-retained, internal, hexagonal abutment (system 1) and a conical implant connected to a solid, internal, conical abutment (system 2). A porcelain-covered, silver-palladium alloy was used as a crown. In each case, a simulated, 100-N vertical load was applied to the buccal cusp. A finite element model was created based on the physical properties of each component, and the values of the von Mises stresses generated in the prosthesis, abutment, implant, and supporting alveolar bone were calculated. In the prostheses, the maximum von Mises stresses were concentrated at the points of load application in both systems, and they were greater in system 1 (148 N/mm²) than in system 2 (55 N/mm²). Stress was greater on the abutment of system 2 than of system 1 on both the buccal (342 N/mm² × 294 N/mm²) and lingual (294 N/mm² × 148 N/mm²) faces. Stress in the cortical, alveolar bone crest was greater in system 1 than in system 2 (buccal: 99.5 N/mm² × 55 N/mm²; lingual: 55 N/mm² × 24.5 N/mm², respectively). Within the limits of this investigation, the stepped cylinder implant connected to a screw-retained, internal hexagonal abutment produces greater stresses on the alveolar bone and prosthesis and lower stresses on the abutment complex. In contrast, the conical implant connected to a solid, internal, conical abutment furnishes lower stresses on the alveolar bone and prosthesis and greater stresses on the abutment.

Key Words: finite element, dental implant, internal hexagon, internal conical joint, alveolar bone, von Mises stresses

INTRODUCTION

Ossseointegrated implants have been used successfully to restore function to fully and partially edentulous patients. Regardless of the high success rate of such dental implants, the literature reveals a significant incidence of technical complications, mainly related to...
excessive occlusal force\textsuperscript{1–3} and implant design.\textsuperscript{4,5} Common technical failures include abutment and prosthetic screw loosening and fracturing,\textsuperscript{6–8} micro displacement of the crown,\textsuperscript{9} of the abutment-implant connection,\textsuperscript{6,10} and single-crown implant restoration.\textsuperscript{11} Although these failures usually do not lead to the loss of an implant, they do represent a significant issue for both patients and clinicians and result in additional costs. To mitigate these difficulties, implants and abutments have undergone a number of modifications, and an extensive variety of implant and abutment geometries and connections are available today.

The design of an implant system, as characterized by its geometry and type of implant-abutment connection, is an important factor in establishing the performance and maintenance of implant osseointegration and implant-supported prostheses since design determines load transmission at both the bone-to-implant and implant-to-abutment interfaces.\textsuperscript{12} The implant-abutment interface initially developed (ie, external hexagonal) is associated with significant clinical complications.\textsuperscript{7} The internal implant-abutment interface, which includes the conical and the internal hexagon, has been introduced into the implant milieu. The conical implant-abutment interface provides a decrease in peak bone-implant interface shear stress compared with the flat top interface\textsuperscript{13} or butt joint.\textsuperscript{14} Furthermore, in a clinical study,\textsuperscript{15} no mechanical complications associated with the prosthetic components (ie, screw loosening, screw breaking, or crown breaking) for either titanium or ceramic abutments were noted during an 8-year period of conical connection use. Krennmair et al\textsuperscript{16} also found a lower incidence (3.5\%) of abutment screw loosening using the conical implant connected to an internal, hexagonal abutment.

Concurrent with the evolution of implant-abutment interface geometry, a variety of new implant body shapes, diameters, thread patterns, and surface topographies has been developed. In the literature, only the individual influence of each of these specific characteristics on stress distribution has been evaluated. Del Valle et al\textsuperscript{17} demonstrated that implants with different geometries but similar diameter apparently show no difference in strain levels on the surrounding bone and that as implant diameter increases, stress magnitude decreases.\textsuperscript{18} However, Siegele and Soltesz\textsuperscript{4} have shown that conical and stepped implants impart distinctly higher stress to the bone than do cylindrical and screw-shaped implants, although stress is dissipated more evenly along the stepped implant compared with the straight implant.\textsuperscript{18}

The aim of this study was to evaluate the influence of 2 commercially available dental implant systems (system 1, an 11.0 × 3.8-mm, stepped cylinder implant connected to a screw-retained, internal hexagonal abutment, vs system 2, an 11.0 × 3.5-mm, conical implant connected to a solid, internal, conical joint) on stress distribution in the prosthesis, abutment, implant, and supporting alveolar bone under simulated occlusal forces, employing a finite element analysis.

MATERIALS AND METHODS

A 2-dimensional, finite element model was created based on the physical properties of the implant, prosthesis, and surrounding bone. The implants and abutments evaluated were as follows:

1. System 1: a stepped cylinder implant (length = 11 mm, external diameter = 3.8 mm; Frialit 2, Friadent, Mannheim, Germany) connected to a screw-retained, internal hexagonal abutment (length = 6.5 mm, diameter = 3.8 mm, angle = 0; EstheticBase, Friadent).
2. System 2: a conical implant (length = 11 mm, external diameter = 3.5 mm; Ankylos, Degussa, Hanau, Germany) connected to a solid, internal, conical abutment (length = 6 mm, diameter = 4.5 mm, angle = 0; straight standard abutment; Ankylos, Degussa).

For the prostheses, a silver-palladium alloy (Degudent Degussa) was used as the crown framework material, which was covered with porcelain (Degussa). Porcelain and metal thicknesses were the same in both systems. Direct contact between the abutment and the prosthesis was assumed.\textsuperscript{19} The bone model was obtained from a tomograph of a patient with a missing lower molar. The bone was classified as type 2, which consisted of a thin layer of cortical bone surrounded by a core of dense trabecular bone,\textsuperscript{20} and was assumed to exhibit a solid pattern within the cortical bone.\textsuperscript{18} A fixed bond (complete load transfer) between the bone and the implant over the entire interface and complete contact (only compression transfer) were also assumed.

The implants, abutments, and prostheses were mounted and embedded in a resin cylinder (T-208, Rede Fibra, São Paulo, Brazil). Vestibular-lingual sections of the mounted components from each system were obtained using a saw (Labcut 1010, Excel Technologies Inc, Enfield, Conn). These sections were digitized by employing an image analysis system.
(Optical Measurement Inspection System, Sprint, Optical Roi Instruments, San Jose, Calif) and were magnified ×40. The data were acquired using appropriate computer software (AUTOMAP 6, Microsoft, Redmond, Wash).

The digital images of the sections of bone, implants, and prostheses were transferred to a second software system (AUTOCAD version 14, Autodesk Inc, San Rafael, Calif). The images representing the real implant and abutment dimensions and the geometries and values assumed for Young’s moduli and Poisson’s rate (Table) were then fed into a further software program (MSC PATRAN, MSC Software Corporation, Santa Ana, Calif) to produce static, finite element analyses of the structures. The elastic parameters for all the components were obtained from the literature or from the manufacturers’ specifications. In all, the finite element model consisted of 7600 elements with 8000 nodes.

Simulated, 50-N vertical loads were applied to the buccal and lingual cusp ridges of the buccal cusp of the implant prostheses (for a total loading of 100 N). Values for the von Mises stresses generated on the prosthesis, abutment, implant, and bone adjacent to the implant were thus calculated.

**RESULTS**

The magnitudes of the von Mises stresses obtained are provided in Figure 1 (system 1) and Figure 2 (system 2).

In the prostheses, the maximum von Mises stresses were concentrated at the points of load application on the occlusal surfaces in both systems. However, stress was greater in system 1 (148 N/mm²) than in system 2 (55 N/mm²).

![Figure 1](image1.png)

![Figure 2](image2.png)

**Figure 1.** Buccolingucl section of system 1 showing the distribution of von Mises stresses under a 100-N vertical load.
The highest von Mises stresses were found in the abutments in both systems. However, stress was greater on the abutment of system 2 than of system 1. Greater stress was found in the cervical region of system 2 than of system 1 on both the buccal (342 N/mm$^2$ × 294 N/mm$^2$) and lingual (294 N/mm$^2$ × 148 N/mm$^2$) faces.

In the implants, the von Mises stresses were similar in both systems; the greatest stress was concentrated on the cervical portion.

In both systems, the von Mises stresses were greater on the cortical bone in direct contact with the implants and on the alveolar bone crest and apex than on the trabecular bone. The stresses on the buccal face of the cortical, alveolar bone crest were greater in system 1 than in system 2 (99.5 N/mm$^2$ × 55 N/mm$^2$). The values of the von Mises stresses generated on the lingual, cortical alveolar bone were also greater in system 1 than in system 2 (55 N/mm$^2$ × 24.5 N/mm$^2$).

A decrease in the von Mises stresses from the cervical region to the apex was also seen in the cortical alveolar bone crest.

In the trabecular bone, system 2 showed lower von Mises stresses than did system 1 (7 N/mm$^2$ × 24.5 N/mm$^2$), although in both systems, higher stresses were found in the apical region of the trabecular bone.

DISCUSSION

The present study discloses an important finding: system 2 produces lower stresses on the alveolar bone and prosthesis and greater stresses on the neck portion of the abutment-prosthesis complex when compared with system 1.

In the prostheses, the maximum von Mises stresses were concentrated at the points of load application on the occlusal surface in both systems, being greater in system 1 than in system 2. These findings suggest that system 2 may provide superior clinical performance in cases of higher occlusal loads. However, clinical trials are necessary to test this hypothesis.

This study also shows that the greatest von Mises stresses were concentrated in the neck portion of the abutment-prosthesis complex in both systems, which may be associated with the frequent complications, including screw loosening and abutment or retaining screw fracturing, reported in clinical studies. The high incidence of screw loosening of up to 40% has
been reported for the external, hexagonal abutment connection.\textsuperscript{6,10} In contrast, a far lower rate of abutment loosening with conical implant abutment and internal hexagonal connections has been found.\textsuperscript{16,22} In the cervical region, the von Mises stresses were greater on the abutment of system 2 than of system 1. However, clinical studies have shown minimal screw loosening (from 0.007% to 5.3%) and no screw fractures using the conical joint.\textsuperscript{15,22,23} To our knowledge, no study has compared the internal hexagonal and conical abutments. When compared with the external joint or butt joint, the internal conical joint seems to be more stable clinically\textsuperscript{24} and exhibits superior strength.\textsuperscript{24,25} In contrast to the present findings, Alkan et al\textsuperscript{26} have shown that the maximum stresses in 3 different implant systems fell on the abutment and the prosthetic screw.

The cement layer was not modeled in this study. Because our objective was to examine the pattern of stress distribution on the implant component, prosthesis, and bone, direct contact was assumed between the prosthesis and the abutment in both systems. As shown previously, the influence of the cement layer on stress distribution is negligible.\textsuperscript{27}

In our study, the von Mises stress was greater on the buccal than lingual portion of the abutment-prosthesis complex, which resulted in a slight displacement of the crown in the buccal direction. Sakaguchi and Borgersen\textsuperscript{28} have associated the separation between a gold screw and the crown with this greater stress on the buccal compared with lingual portion of the abutment-prosthesis complex. Figures 1a and b show a red line representing the original crown position and that subsequent to force application. Cechreli and others\textsuperscript{29} also noted horizontal implant displacement resulting from the application of vertical or oblique loads. Micromotion is an important issue because it can produce fracture and loosening of the screws\textsuperscript{29} and bone loss\textsuperscript{30} and seems to be reduced with 5.0-mm diameter implants compared with the use of 3.75-mm implants.\textsuperscript{9} In our study, the displacement of the crown was similar in both groups.

For the implant, the von Mises stresses were similar in both systems, which is consistent with the findings of Holmgren et al\textsuperscript{18}; however, other studies suggest that conical and stepped implants impart distinctly higher stresses than do cylindrical implants.\textsuperscript{4} In the present study, greater stresses were concentrated in the cervical region of the implant, where the stress magnitude was also greater on the cortical bone in both systems. We also found that the von Mises stresses were greater in system 1 than in system 2 on the cortical alveolar bone crest. Thus, given the present findings, we believe that the conical abutment-implant connection may improve stress dissipation on the crestal alveolar bone, in agreement with literature findings,\textsuperscript{13,18} and may decrease the marginal bone resorption resulting from stress accumulation in the bone. Further support for this notion is that the system 2 implant has a smaller diameter than system 1 (3.5 vs 3.8 mm), which would increase stress magnitude on the surrounding bone.\textsuperscript{18} However, clinical trials are necessary to evaluate this hypothesis. Finite element models have their limitations because the mechanical properties and the nonlinear behavior of biological tissues cannot be accurately predicted and the cortical and trabecular bone regions are considered to be bonded to the implant. On the other hand, finite element models have the advantage of allowing the evaluation of specific factors without the influence of other variables.

Considering the lower stresses on the bone in system 2, this system may exhibit better behavior in more trabecular bone, which has been suggested previously.\textsuperscript{12,15} The greater stress noted in the alveolar bone crest may be associated with the saucerization effect seen around the implant head after functioning for a fairly short time.\textsuperscript{2} Hermann et al\textsuperscript{31} have associated the saucerization effect with bone adaptation through a self-limiting phenomenon.

In the present study, a simulated vertical load was applied to the buccal and lingual cusp ridges of the buccal cusp of the implant prosthesis, because in a single-unit implant restoration, mainly in the molar region, the restoration itself is usually wider than the implant fixture, creating the potential for off-axial loading.\textsuperscript{32} Furthermore, under clinical conditions, occlusion is represented by a combined location of load application.\textsuperscript{33}

Within the limits of this study, the stepped cylinder implant connected to a screw-retained, internal hexagonal abutment exhibits greater stresses on the alveolar bone and prosthesis and lower stresses on the abutment complex. In contrast, the conical implant connected to a solid internal, conical abutment (system 2) furnishes lower stresses on the alveolar bone and prosthesis and greater stresses on the abutment.

\textbf{REFERENCES}


