Biomechanical Effect of Prosthetic Connection and Implant Body Shape in Low-Quality Bone of Maxillary Posterior Single Implant-Supported Restorations

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Purpose: *Dental implant macrogeometry parameters, such as the prosthetic connection and implant body shape, can influence the biomechanical behavior of the restoration. Using tridimensional finite element analysis (3D-FEA), this study evaluated the biomechanical behavior of two implant macrodesign parameters (prosthetic connection and implant body shape) in low-quality bone.* ***Materials and Methods:*** *Four groups were obtained by the combination of external hexagon and Morse taper connections, and cylindrical and conical body shapes. Implants (4ø × 10-mm) with a microthread collar and triangular thread shape received a single abutment and monolithic zirconia crown on the maxillary first molar. Bone was constructed on the basis of cross-sectional images of the posterior human maxilla obtained by cone beam computer tomography. A 200-N axial loading was distributed on five points of the occlusal surface. Data were acquired as shear stress ($_{\tau\text{max}}$, in megapascals) and strain ($_{\varepsilon\text{max}}$, in micrometers) in the cortical and trabecular bone.* ***Results:*** *The external hexagon groups generated higher shear stress/strain values compared with Morse taper groups in the cortical bone, regardless of implant body shape. In the trabecular bone, the highest $_{\tau\text{max}}$ and max values were observed in the Morse taper conical implant group (6.94 MPa and 21.926 × 10^{-4} µm, respectively), and the lowest values were observed in the external hexagon cylindrical implant group (4.47 MPa and 9.3155 × 10^{-4} µm, respectively).* ***Conclusion:*** *The magnitudes of shear stress and strain in the peri-implant region of low-quality bone was lower with the use of Morse taper connection and cylindrical implants compared with external hexagon connection and conical implants.* Int J Oral Maxillofac Implants 2016;31:xxx–xxx. doi: 10.11607/jomi.4133

Keywords: *dental implant, finite element analysis, implant body shape, osseointegration, prosthetic connection*

The biomechanical behavior of implants has been the subject of research in both dentistry and engineering fields, with the aim of providing high success rates in the rehabilitation of partially or totally edentulous patients.[1] Although the success rate can vary in different areas of the mouth and different patients, lower success rates have been associated with implants placed in the posterior maxilla and in sites characterized by thin cortical bone or low trabecular density.[2,3] The challenge of improving this scenario underlies scientific research to identify the implant macrodesign parameters involved in the stress/strain magnitude.[4,5] Excessive occlusal loads can induce microdamage at the bone-implant interface, implant fracture, screw loosening, or bone resorption. In this context, the prosthetic connection and implant body shape may have major roles in the stress and strain dissipation that compromise osseointegration.[6]

Bone tissue responds differently depending on the load type.[7] Shear stress is considered to be the most harmful force to the bone.[8] Strain is harmful to the bone-implant interface because strain can cause micromotion, which can lead to osseointegrative failure.[2] Depending on the prosthetic connection and body shape, the force may vary in magnitude, concentration, and distribution.[9,10] Studies have been conducted

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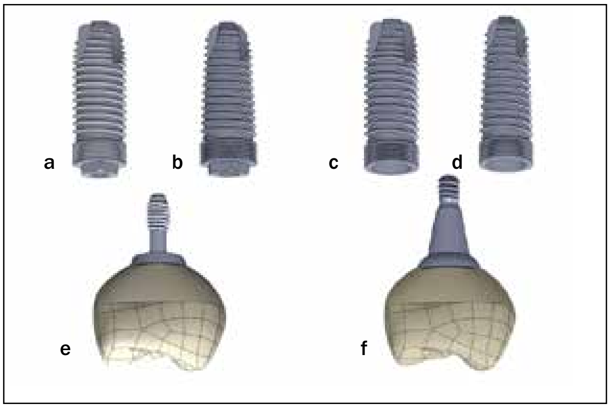

Fig 1 Schematic illustration of the four groups used in the study and their prosthetic components. (*a, b*) External hexagon and (*c, d*) Morse taper implants; (*a, c*) cylindrical and (*b, d*) conical body shapes. Also shown are the zirconia crown, abutment, and abutment screw used for the *(e)* external hexagon and *(f)* Morse taper connections.

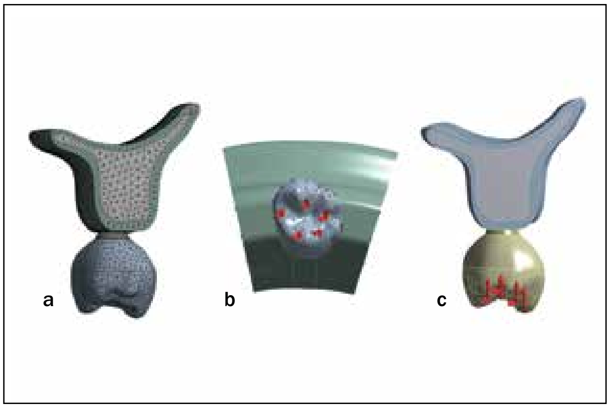

Fig 2 *(a)* Mesh generated manually with 0.5-mm elements after convergence analysis (5%). *(b, c)* Axial loading distributed on the occlusal surface of the zirconia crown.

to analyze these parameters in bone of higher density.[4,6,11–13] However, few studies have evaluated implant macrodesign parameters in low-quality bone. Therefore, the purpose of the present study was to investigate the magnitude and concentration of shear stress and strain in osseointegrated implants with different prosthetic connections and implant body shapes inserted in low-quality bone.

MATERIALS AND METHODS

Experimental Design

With the help of computer-aided design software (SolidWorks 2014, SolidWorks), four implant models were modeled with two types of prosthetic connections (external hexagon and Morse taper) and two body shapes (cylindrical and conical), as shown in Fig 1. Implant dimensions were 10 mm in length and 4 mm in diameter with a microthread collar and triangular thread shape. Cortical and trabecular bone were modeled based on a cross-sectional image of the human posterior maxilla acquired by cone beam computer tomography, to simulate bone architecture in the region of interest. The thickness of cortical bone around the implant neck was set at 1.4 mm. Implants were positioned at the crestal bone level and restored with titanium abutments and cemented zirconia crowns.

Numerical Analysis

For mesh acquirement and numerical analysis, all models were exported to finite element analysis (FEA) software (Ansys Workbench 10.0, Swanson Analysis). Convergence analysis (5%) was performed as a mesh refinement process to improve the accuracy of the results. The mesh was generated with 0.5-mm quadratic tetrahedral elements (Fig 2). Materials used in the present study were considered isotropic, homogenous, and linearly elastic, except for the cortical and trabecular bone that were assumed to be anisotropic. Mechanical properties of materials were taken from the literature (Table 1).[14–17]

Bonded contact type between the bone and implant surfaces was used to simulate integration with the bone and with all other contact areas. Models were constrained in all directions at nodes on the mesial and distal borders of the bone segment. A 200-N axial loading was applied and distributed on five points of the occlusal surface of the crown (Fig 2). The magnitudes and distributions of the shear stress ($_{\tau \max}$, in megapascals) and strain ($_{\varepsilon \max}$, in micrometers) adjacent to the peri-implant interface were investigated for all models using tridimensional FEA (3D-FEA).

RESULTS

Higher shear stress/strain values in cortical bone were found in the external hexagon groups compared with the Morse taper groups. The external hexagon groups showed three times the amount of shear stress/strain in cortical bone, regardless of the implant body shape (Table 2). The connection type also influenced shear stress/strain in trabecular bone, with lower magnitudes of shear stress/strain being observed in the external hexagon groups. In trabecular bone, the shear stress/strain values were higher in conical than in cylindrical implants (Table 2).

In cortical bone, higher shear stress/strain values were found coronally adjacent to the implant-abutment interface. This effect was more evident in the external hexagon than in the Morse taper groups (Figs 3

Table 1 Properties of Materials Used in the FEA Models

	Young's modulus (E) (MPa)		Shear modulus (G) (MPa)		Poisson ratio (δ)	
Cortical bone[14]	E_x	12,600	G_{xy}	4,850	δ_{xy}	0.30
	E_y	12,600	G_{yz}	5,700	δ_{yz}	0.39
	E_z	19,400	G_{xz}	5,700	δxz	0.39
Trabecular bone [11,14]	E_x	1,150	G_{xy}	6,800	δ_{xy}	0.001
	E_y	2,100	G_{yz}	4,340	δ_{yz}	0.32
	E_z	1,150	G_{xz}	6,800	δxz	0.05
Titanium (implant and abutment)[15]	104,000		38,800		0.34	
Cement[16]	17,000		14,500		0.30	
Zirconia[17]	210,000		33,000		0.31	

The subscripts x, y, and z correspond to the axis of the global coordinate system.

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Table 2 Maximum Shear Stress (MPa) and Strain Values (×10^{-4} µm) in the Peri-implant Bone in Accordance with the Type of Prosthetic Connection (EH and MT) and Implant Body Shape (Cylindrical and Conical)

	Cylindrical		Conical	
Bone response	**EH**	**MT**	**EH**	**MT**
Shear stress				
Trabecular bone	4.4755	5.0731	6.8529	6.9436
Cortical bone	12.063	4.6433	12.444	4.773
Strain				
Trabecular bone	9.3155	9.3675	21.753	21.926
Cortical bone	10.49	3.5089	10.461	3.6207

EH = external hexagon; MT = Morse taper.

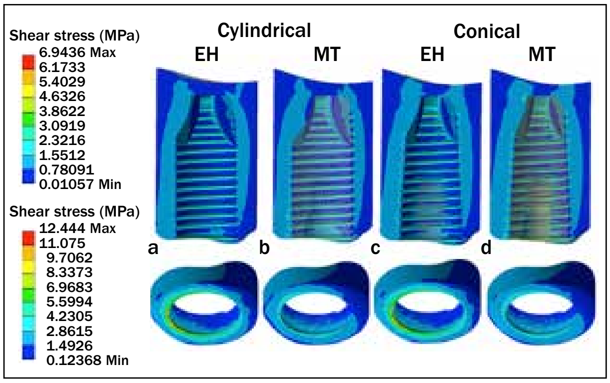

Fig 3 Shear stress in the trabecular *(top)* and cortical *(bottom)* bones in the four groups, with *(a, b)* cylindrical and *(c, d)* conical implant body shapes, and with *(a, c)* external hexagon and *(b, d)* Morse taper connections. EH = external hexagon; MT = Morse taper.

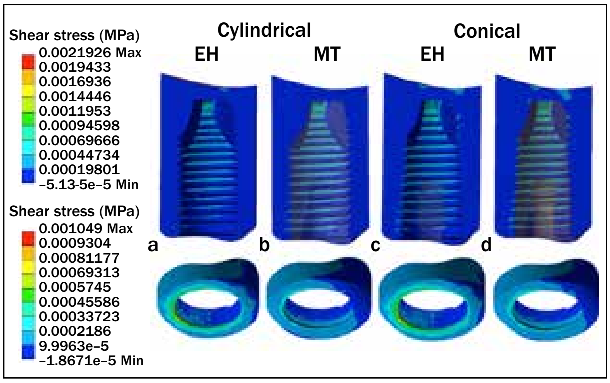

Fig 4 Strain in the *(top)* trabecular and (*bottom*) cortical bones in the four groups of implants, with (*a*, *b*) cylindrical and (*c*, *d*) conical implant body shapes, and with (*a*, *c*) external hexagon and (*b*, *d*) Morse taper connections. EH = external hexagon; MT = Morse taper.

anda 4). In trabecular bone, the highest shear stress/strain values were concentrated in the thread crest and implant apex, especially in conical implants, whereas the lowest shear stress/strain values were found at the thread base (Figs 3 and 4).

DISCUSSION

FEA is a useful tool for obtaining internal biomechanical behavior in complex models that could not be evaluated by fatigue laboratory tests or clinical trials.[6] In this study, four 3D models with different prosthetic connections (external hexagon and Morse taper) and implant body shapes (cylindrical and conical) were constructed to evaluate shear stress and strain in low-quality (type IV) cortical and trabecular bone in the posterior maxilla. In low bone quality, the macrodesign of the implant is important to enhance the primary stability. Most commonly, FEA studies only examine the effect of a single implant macrodesign parameter.[4,12] The results in this study highlight the clinical relevance of the interaction between these parameters on the biomechanical behavior of the peri-implant bone. Underestimating this interaction may compromise the interpretation of the results, which consist of a set of interrelated parameters. In this study, the type of prosthetic connection influenced the shear stress/strain in both cortical and trabecular bone, but the implant body shape affected shear stress/strain only in trabecular bone.

The external hexagon connection type has been associated with higher rates of crestal bone resorption,[18] due to the higher stress generated at the cervical area, greater abutment micromovements, and formation of microgaps that lead to peri-implant tissue inflammation.[6,13,19,20] This microgap present at the crestal bone level is subject to bacterial colonization of the external hexagon implant-abutment interface. The inflammation acts as a chronic factor that causes an apical movement of the biologic width at the expense of the crestal bone.[21] In the present study, the external hexagon groups provided three times the shear stress and strain on top of the marginal crestal bone compared with the Morse taper groups. In previous biomechanical studies,[10,13,19] the maximum stress and strain occurred at the top marginal surface of the bone in flat-top interfaces, such as external hexagon connections, but more apically in conical interfaces, such as Morse taper connections. Higher shear stress and strains observed to external hexagon connections with numerical simulation of the present study have indicated the risk of bone loss for regions around the implant neck, mainly in the posterior region with low-quality bone. This type of connection system may allow repetitive micromovements between the parts during the clinical function, which might lead to an accumulation of bacteria at its microgap, localized inflammation, and bone resorption.[21] Micromovements occur due to its reduced hexagon height and to the abutment screw being responsible on its own to maintain the implant-abutment interface.[22]

In the present study, the low shear stress/strain values found in the Morse taper groups can be explained by the differences in the internal taper interface surface area when compared with straight interface and reduced hexagon size found in the external hexagon groups. The Morse taper connection promotes better mechanical friction between the external wall of the abutment and internal wall of the implant, and no rotation of the abutment is observed. Therefore, the lateral wall of the abutment helps dissipate the vertical forces to the implant.[22] Lower stress and strain at the cervical area have been shown to contribute to bone preservation, whereas higher stress at the tip area can be a risk factor for bone resorption,[19] as was observed in the present study for the external hexagon connection.

Randomized controlled clinical trial studies with 1 year follow-up postloading that compared implants positioned at crestal level with external hexagon and Morse taper prosthetic connections revealed statistically significant differences in both vertical and horizontal marginal bone loss changes between the two investigated implants.[23–25] Better radiologic results were observed for Morse taper in all periods of the investigation. A positive effect on peri-implant marginal bone preservation and less crestal bone loss were observed to the Morse taper prosthetic connection than implants restored with a standard protocol (external hexagon connection). Implants restored according to a platform-switching concept using a conical implant-abutment, such as the Morse taper design, provides better abutment fit, stability, and seal performance, and less stress concentration to the peri-implant bone. This biomechanical performance could explain the differences between external and Morse-taper connections and its bone loss pattern in clinical situations.

For both prosthetic connection types, a microthread collar was used on the implant neck. Microthreads, present on the cervical region of the implant in contact with cortical bone, may induce better dissipation of the occlusal load and help to preserve the peri-implant crestal bone. Clinical studies[26,27] support the notion that microthreads at the implant neck provide minimal bone resorption and stable peri-implant marginal bone around implants. The shear stress/strain concentrations were decreased in the thread crest and implant apex in trabecular bone with the external hexagon connection, whereas the shear stress/strain concentrations were increased in these areas with the Morse taper connection, regardless of the implant body shape.

The type of implant body design only influenced stress/strain in the trabecular bone. Cylindrical implants induced lower shear stress and strain than conical implants, although the conical implant presented better primary stability. Higher insertion and removal torque forces have been reported to tapered implants.[28] In addition, this type of implant shape has the advantage of achieving primary stability more easily,[2] but also increases the stress in the surrounding bone and can induce more bone loss.[7,29] Some FEA studies have revealed that cylindrical implants are more associated with low stress levels in trabecular bone, which leads to bone preservation.[5,30,31] The highest shear stress/strain concentrations were found in the thread crest and implant apex, especially in conical implants. This finding can be explained by the geometric discontinuities of the thread crest and the small radius of curvature in the apical region of the conical implant.[32] The numerical findings of the present study are in accordance with a study that examined retrospectively the clinical outcome of external hexagon implants with tapered and cylindrical shapes on peri-implant bone remodeling after the first year of implant placement and loading.[33] This clinical study revealed a significant difference in bone level between both types of implants, with tapered implants losing more bone than cylindrical implants, regardless of maxilla or mandibular position. Therefore, cylindrical implant body shape seems to be able to maintain the osseointegration process around trabecular low-quality bone after loading restoration better than tapered-shape implants.

However, in a FEA study by Huang et al,[11] the stress decreased in trabecular bone when a conical body shape was used. The authors attributed this effect to the increased thread depth in the conical body implant, which increased the bone-implant contact area. In the cylindrical implant, the authors used a lower thread depth. The difference in thread design between the implants could have masked the real effect of the implant body shape on the stress dissipation. In the present study, all of the implants were modeled with a similar thread depth. Therefore, the results were compatible with the real effect of the implant body shape and were not influenced by other implant macrodesign parameters. Changes in the depth and shape of the threads are important in the biomechanics and bone-implant interface.

This study analyzed only axial loading in the test groups. Biomechanical studies have demonstrated that nonaxial loading to single implant-supported restoration had an influence on the stress distribution when compared with axial loading, with greater increase of stress and strain in the peri-implant bone due to the components of the lateral forces tending to increase and also to the momentum of force.[13,34] The effects of nonaxial loading in the posterior maxilla would be investigated in future studies.

CONCLUSIONS

The magnitudes of shear stress and strain in the peri-implant region of low-quality bone was lower with the use of the Morse taper connection and cylindrical implants compared with the external hexagon connection and conical implants. This improvement in stress and strain concentration could decrease the clinical risk of bone loss in the posterior region of the maxilla.

ACKNOWLEDGMENTS

This work was supported by the Coordination of Improvement of Higher Level Personnel (CAPES-PROEX; Brasília, DF, Brazil, grant # 0235083/ Dental Clinic). The authors reported no conflicts of interest related to this study.

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