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To Evaluate the Stress and Strain Distribution at Bone Implant Interface as a Consequence of Progressive Marginal Bone Loss - A Finite Element Analysis

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Abstract

Introduction: This study was undertaken to evaluate the pattern of stress and strain distribution at the bone–implant interface when progressive marginal bone loss has occurred, using finite element analysis.

Materials and Methods: The geometric models of the implant and mandibular bone were generated. Five models were created in accordance with the needs of the study. Different 3D geometric models of a dental implant with a PFM crown reciprocating the anatomy of the mandibular first molar were generated with varying amounts of bone loss. The models generated included: no crestal bone loss (M0), 1 mm vertical and 0.5 mm horizontal bone loss (M1), 2 mm vertical and 1 mm horizontal bone loss (M2), 3 mm vertical and 1.5 mm horizontal bone loss (M3), and 6 mm vertical and 2.5 mm horizontal bone loss (M4). A force of 150 N was applied to the central occlusal fossa at 6° relative to the axial axis of the implant.

Results: Stress distribution was observed to be highest in the control group (M0) in trabecular bone, while it was highest in M4 in the implant body and in the complete assembly of bone, implant, and crown. For cortical bone, the stress distribution was found to be highest in study model M1.

Strain distribution was observed to be highest in study model M0 (the control group), whereas strain values increased from study model M0 to study model M4 in trabecular bone and the implant body.

Conclusion: With an increase in bone loss, maximum strain increased in trabecular bone, on the implant body, and in the complete implant–bone–crown assembly, whereas the strain decreased with bone loss in cortical bone.

Keywords: Finite element analysis, implant, marginal bone loss, strain distribution, stress distribution.

Introduction

While endosseous implants have shown high success rates, the issue of crestal bone resorption still remains a focal point. Various theories have been proposed to elucidate this phenomenon, encompassing factors such as trauma during second-stage surgery, peri-implantitis related to plaque buildup, increased force transmission from occlusal loads during tooth contact, and limitations of the rigid bone–implant interface in absorbing physiological forces without a periodontal ligament, especially in cases of thin bone.[1]

Various types of stimuli, including biomechanical forces in the dental prosthesis and the potential presence of inflammation (mucositis and peri-implantitis), can cause bone loss around implants. Peri-implant disease is not an uncommon condition in which plaque and its by-products in a susceptible host represent the primary etiology, as demonstrated by its cause-and-effect relationship. Several local and systemic factors have been proposed and associated with an increased risk of peri-implantitis, such as smoking, diabetes, previous history of periodontal disease, poor plaque control, and occlusal overload.[2]

Peri-implantitis is a progressive inflammatory condition that occurs around a dental implant. This inflammation leads to the breakdown of the bone supporting the implant, eventually resulting in implant failure. Signs of peri-implantitis include bleeding, pus formation, deeper pockets around the implant, implant mobility, and visible bone loss on radiographs.[3] Cocci and non-motile rods present in the subgingival microflora associated with peri-implantitis are among the most important pathogens implicated in the failure of dental implants.[4]

Marginal bone loss will unavoidably occur as a result of currently used implant systems. Various studies have demonstrated that bone loss occurs in the crestal area of cortical bone and progresses further apically. During the first year, crestal vertical bone loss of approximately 1 mm is quite common, followed by about 0.1 mm bone loss in subsequent years. Trabecular bone has a lower elastic limit compared to cortical bone and therefore undergoes greater deformation in peri-implant bone loss. When functional load is applied to an implant in the presence of bone loss, a higher ratio of stress as well as strain is observed in trabecular bone. Increased strain in bone can lead to pathological overstress, which, along with parafunctional habits, may further compromise the bone formation process.[5]

One of the major complications of dental implant procedures is peri-implantitis. Finite element analysis is helpful in studying the stress distribution in the bone surrounding the implant. The stress and strain distribution can be evaluated in cortical bone, trabecular bone, and the implant. Each finite element studied is combined to represent the entire structure for analysis. However, the dental implant–bone structure is complex in nature. Finite element analysis can be further improved through mesh refinement in the model.[6]

The present research was focused on evaluating stress and strain distribution at the bone–implant interface as a consequence of progressive marginal bone loss using finite element analysis.

Materials and Methods

The present study was conducted in the Department of Prosthodontics and Crown & Bridge, Bhojia Dental College & Hospital, Baddi, Solan, Himachal Pradesh, India, and Product Design and Development Company, Tamil Nadu, India.

Computational Facilities Used for the Study

A 3D finite model was generated on a computer using Pro/ENGINEER software (Parametric Technology Corporation, Needham, MA, USA). ANSYS Workbench software (ANSYS 2020, Inc., USA) was used to analyze stresses and strain.

Methodology

The models of the implant and surrounding bone were constructed. Finite element analysis was performed using ANSYS software version 2020. A Type-3 edentulous posterior mandible bone section was designed according to the classification by Lekholm and Zarb.[7] The bone surrounding the implant was 23 mm in height and 12 mm in width, with a 1 mm thick cortical bone section, while the remaining portion consisted of trabecular bone (Fig. 1).

Meshing was created using ANSYS software. The physical properties of the implant and bone were incorporated to form the 3D model (Table 1). A bidirectional transferable system called the Initial Graphics Exchange Specification was used in conjunction with ANSYS Workbench (ANSYS 2020, Inc., USA).

Von Mises stress was used to assess stresses in bone and implant structures. A color scale representing stress values was displayed, ranging from 0 MPa (blue) to the highest values (red). The models were meshed using tetrahedral, ten-noded elements. A finer mesh was generated around the implant–bone interface. The models consisted of different numbers of nodes and elements.

Constraints and Loads

A 150 N axial force at an angulation of 6° was applied buccolingually to the center of the occlusal fossa of the molar. For this load, numerical Von Mises stress and strain distributions were analyzed from the finite element models (Figs. 2–6).

Results

The present in vitro study evaluated and compared the impact of peri-implant marginal bone loss in models with different amounts of bone loss when occlusal load was transferred to the supporting bone through stress and strain distribution.

Under all assumptions, a load of 150 N was applied to the central occlusal fossa of the crown in the vestibulo-lingual direction at a 6° angle relative to the axial axis of the implant, thereby simulating physiological loading conditions in a mandibular premolar-molar region.

The maximum Von Mises stress values in:

- Cortical bone was noted in model M1 (1 mm vertical and 0.5 mm horizontal crestal bone loss).
- Trabecular bone was noted in the control group (no bone loss).
- Implant body were noted in model M4 (6 mm vertical and 2.5 mm horizontal crestal bone loss).
- Maximum total stress in the complete model was noted in M4 (6 mm vertical and 2.5 mm horizontal crestal bone loss) (Fig. 7, Table 2).

The maximum strain values in:

- Cortical bone were noted in the control group (no bone loss).
- Trabecular bone were noted in M4 (6 mm vertical and 2.5 mm horizontal crestal bone loss).
- Implant body were noted in M4 (6 mm vertical and 2.5 mm horizontal crestal bone loss).
- Maximum total deformation in the complete model was noted in M4 (6 mm vertical and 2.5 mm horizontal crestal bone loss) (Fig. 8, Table 3).

Discussion

Implant dentistry has evolved into an evidence-based clinical science supported by well-documented research validating clinical procedures that were previously unsupported. Early research explored techniques and instruments that were contemporary for the methods and materials available at that time. Although many of those implants are still functioning today, advances in research and technology have provided newer materials, improved implant designs, and refined clinical protocols to maintain dental implant health. However, despite improved and predictable clinical success in implantology, peri-implant diseases have been diagnosed with increasing incidence. Numerous conflicting opinions and controversies remain regarding the diagnosis and treatment of these complications. Failure to effectively and promptly diagnose and treat peri-implant disease can lead to increased implant and prosthetic failure.[8]

Prosthetic restorations have also demonstrated an association with peri-implant diseases. There are three main types of implant-abutment connections: platform-switched, butt-joint, and no-interface connections. Bone loss of approximately 1.5–2.0 mm can occur with butt-joint connections due to the presence of a microgap that allows bacterial penetration and colonization. Although platform switching may help prevent or reduce marginal bone loss, contaminated connections can still lead to peri-implantitis and implant failure over time. Additionally, a convex restoration profile may pose an additional risk for bone-level implants.[8,9]

The present study utilized 3D finite element analysis to compare the magnitude of stress and the distribution of strain in peri-implant bone and the implant itself, depending on the presence and magnitude of marginal bone loss.

In the present study, stress analysis in trabecular bone showed that stress decreased with increasing bone loss around cancellous bone. This observation is consistent with the study by Gupta et al., whose FEA analysis evaluating stress distribution around implants with horizontal bone loss concluded that bone loss causes maximum stress around the bone–implant interface and reduced stress in cancellous bone. This finding is clinically relevant, as the ultimate strength of cancellous bone is only 5 MPa compared to 100 MPa for cortical bone.[10]

From the findings of the present study, it can be inferred that loss of cortical bone at the crestal level of the bone–implant interface exposes the softer trabecular bone, which has a greater tendency to resorb compared to cortical bone. The observations indicate higher stress levels with increasing vertical and horizontal bone loss, which may eventually lead to premature implant failure in the long term.

In the present study, it was notable that direct exposure of trabecular bone to oblique forces remarkably decreased stress intensity but substantially increased displacement and strain due to its material property associated with Young’s modulus. The results demonstrate that a 2 mm bone loss around the implant neck almost doubles the strain gradients. Considering that oblique loading also increases implant displacement, the biomechanical consequences could reach clinical significance, as increased strain gradients may lead to an inability of bone to repair and may result in micro-fractures in bone under load.[11]

Within the limitations of finite element analysis, the forces observed represent absolute values and therefore provide only an approximation. Nevertheless, this approach offers valuable insight into the distribution patterns under different conditions and highlights areas where stresses are concentrated. This information can guide the design of restorations to improve force distribution and reduce potential threats to the prognosis of implant-supported restorations. The findings of this study should be correlated with clinical studies.

Conclusion

According to the findings, and within the limitations of this in vitro study, the following conclusions can be drawn:

- Stress distribution was observed to be highest in the control group (M0) in trabecular bone, followed by M1, M2, M3, and M4.
- In the implant body and when the complete assembly of bone, implant, and crown was evaluated, maximum stress was observed in M4, followed by M3, M2, M1, and M0.
- In cortical bone, the stress distribution was highest in study model M1 (1 mm vertical and 0.5 mm horizontal bone loss), followed by M0, M2, M3, and M4 respectively.
- Strain distribution in cortical bone at the bone–implant interface was highest in the control group (M0), followed by M1, M2, M3, and M4.
- Strain values increased progressively from study model M0 to study model M4 in trabecular bone and the implant body.

Furthermore, scope of the study

- Due to the limitations of this study, further research correlating 3D FEA study findings with the biological clinical environment is recommended.

References

1. Assenza B, Scarano A, Petrone G, Iezzi G, Thams U, San Roman F, Piattelli A. Crestal bone remodeling in loaded and unloaded implants and the microgap: a histologic study. Implant Dent. 2003;12(3):235–241.
2. Fu JH, Hsu YT, Wang HL. Identifying occlusal overload and how to deal with it to avoid marginal bone loss around implants. Eur J Oral Implantol. 2012;5:91–103.
3. Lindhe J, Berglundh T, Ericsson I, Liljenberg B, Marinello C. Experimental breakdown of peri-implant and periodontal tissues: a study in the beagle dog. Clin Oral Implants Res. 1992;3(1):9–16.
4. Deppe H, Horch HH, Henke J, Donath K. Peri-implant care of ailing implants with the carbon dioxide laser. Int J Oral Maxillofac Implants. 2001;16(5):659–667.
5. Kitamura E, Stegaroiu R, Nomura S, Miyakawa O. Influence of marginal bone resorption on stress around an implant: a three-dimensional finite element analysis. J Oral Rehabil. 2005;32(4):279–286.
6. Geng J, Yan W, Xu W, editors. Application of the finite element method in implant dentistry. Berlin: Springer Science & Business Media; 2008.
7. Misch CE. Dental implant prosthetics. 2nd ed. St. Louis: Mosby Elsevier; 2015.
8. Juodzbalys G, Kubilius M. Clinical and radiological classification of the jawbone anatomy in endosseous dental implant treatment. J Oral Maxillofac Res. 2013;4(2):e2.
9. Macedo JP, Pereira J, Vahey BR, Henriques B, Benfatti CA, Magini RS, López-López J, Souza JC.

Morse taper dental implants and platform switching: the new paradigm in oral implantology. Eur J Dent. 2016;10(1):148–154.

10. Gupta S, Narayan AI, Balakrishnan D, Narayan S. Effect of peri-implantitis associated horizontal bone loss on stress distribution around dental implants – A 3D finite element analysis. Mater Today Proc. 2020;28(3):1503-1509.

11. Pérez-Pevida E, Chávarri-Prado D, Diéguez-Pereira M, Estrada-Martinez A, Montalbán-Vadillo O, Jiménez-Garrudo A. Consequences of peri-implant bone loss in the occlusal load transfer to the supporting bone in terms of magnitude of stress, strain, and stress distribution: a finite element analysis. Biomed Res Int. 2021; 2021:5596542.

Legend Tables

Table 1: Mechanical properties of materials and fixtures

Material	Component	Young's Modulus (GPa)	Poisson's coefficient
Cortical bone		15	0.39
Trabecular bone		1	0.25
Ti-6Al-4V alloy	Abutment and screw dental implant	107.2 110	0.30 0.35
Cr-Co alloy	Crown structure	218	0.33
Feldspathic ceramic	Crown veneering	65	0.25

Table 2 Von Mises stress (MPa) values in (a) cortical bone, (b) trabecular bone, and (c) implant for no crestal bone loss (control group), 1 mm vertical and 0.5 mm horizontal crestal bone loss, 2 mm vertical and 1 mm horizontal crestal bone loss, 3 mm vertical and 1.5 mm horizontal crestal bone loss, and 6 mm vertical and 2.5 mm horizontal crestal bone loss.

Table 2:

Model	Cortical Bone	Trabecular Bone	Implant	Total stress
Control Group	1.5981	12.924	26.006	25.994
M1	14.511	2.349	29.257	29.237
M2	5.3785	3.7332	31.056	26.61
M3	5.1218	4.3336	31.074	31.044
M4	3.7274	1.3109	41.379	41.333

Table 3 Von Mises strain values in (a) cortical bone, (b) trabecular bone, and (c) implant for no crestal bone loss (control group), 1 mm vertical and 0.5 mm horizontal crestal bone loss, 2 mm vertical and 1 mm horizontal crestal bone loss, 3 mm vertical and 1.5 mm horizontal crestal bone loss, and 6 mm vertical and 2.5 mm horizontal crestal bone loss.

Table 3:

Model	Cortical Bone	Trabecular Bone	Implant	Total deformation
Control Group	0.0056908	0.0055473	0.0071222	0.0073069
M1	0.005601	0.0063012	0.0076623	0.0074264
M2	0.0036106	0.0060595	0.0078793	0.0081685

M3	0.0030541	0.0066402	0.0087115	0.0090667
M4	0.0029224	0.0074509	0.013757	0.014737

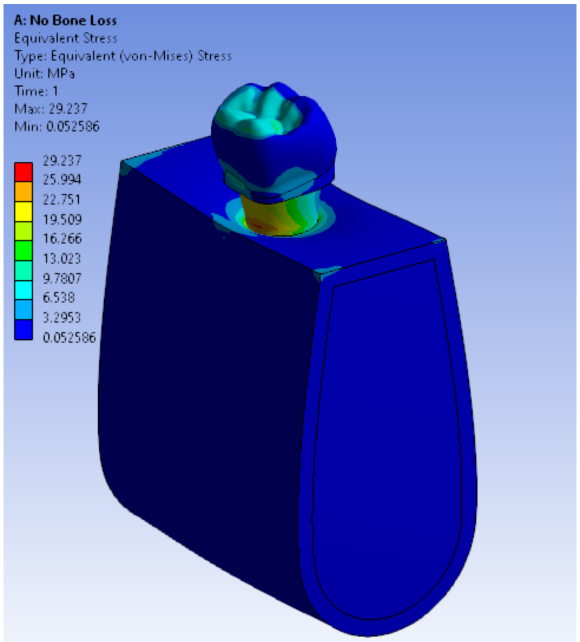

Figure 1: Complete model assembly.

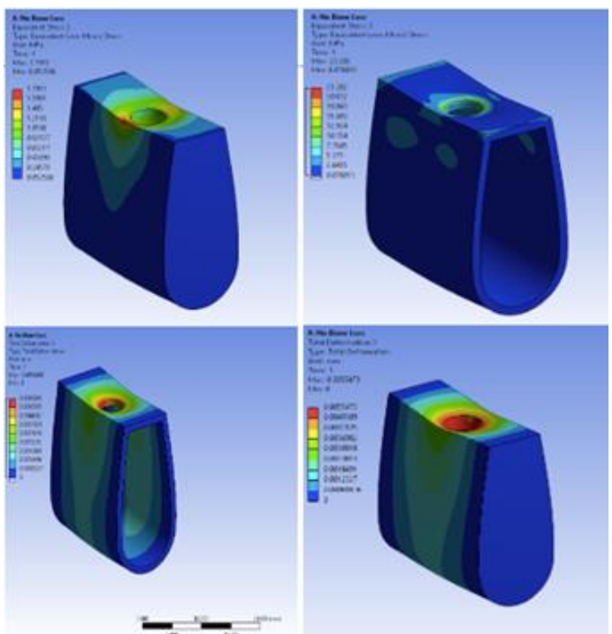

Figure 2: Stress distribution in (A) cortical bone and (B) cancellous bone, and strain distribution in (C) cortical bone and (D) cancellous bone in models with no bone loss.

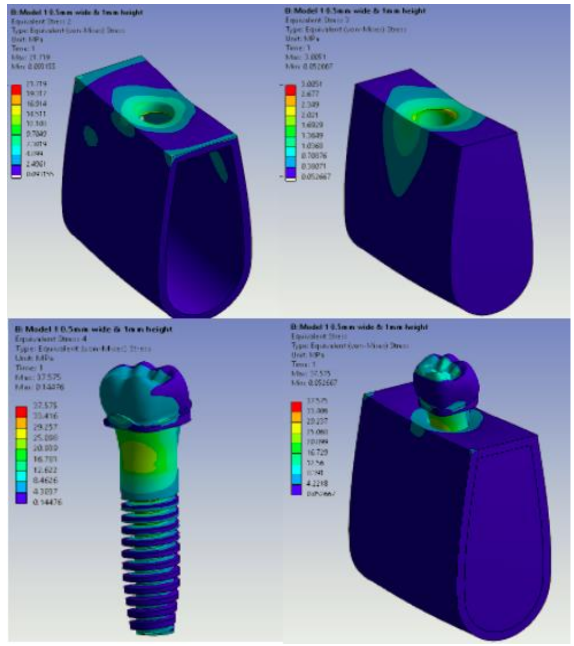

Figure 3: Stress distribution in (A) cortical bone and (B) cancellous bone, and strain distribution in (C) cortical bone and (D) cancellous bone in models with 1 mm bone loss.

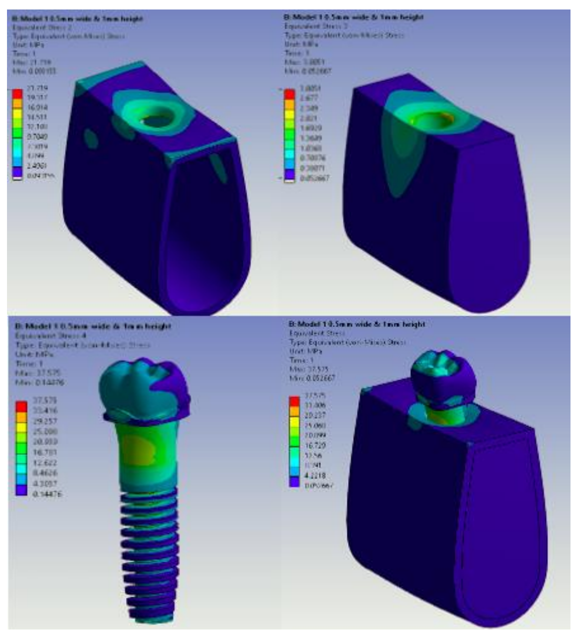

Figure 4: Stress distribution in (A) cortical bone and (B) cancellous bone, and strain distribution in (C) cortical

bone and (D) cancellous bone in models with 2 mm bone loss.

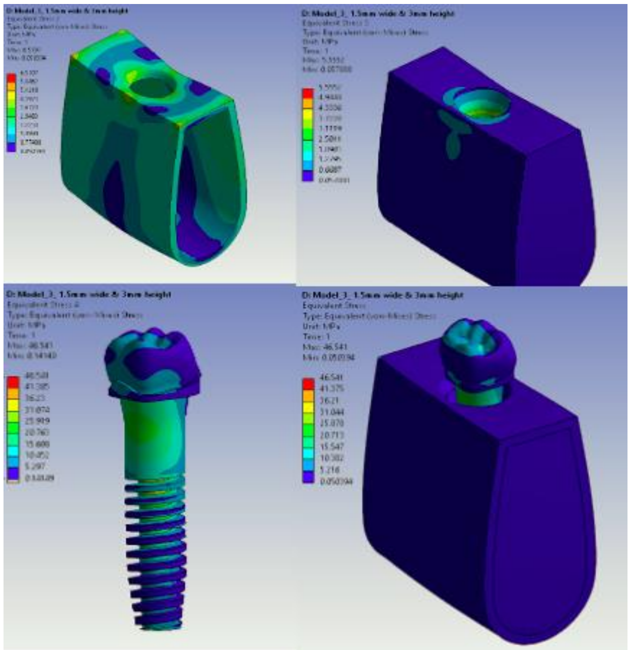

Figure 5: Stress distribution in (A) cortical bone and (B) cancellous bone, and strain distribution in (C) cortical bone and (D) cancellous bone in models with 3 mm bone loss.

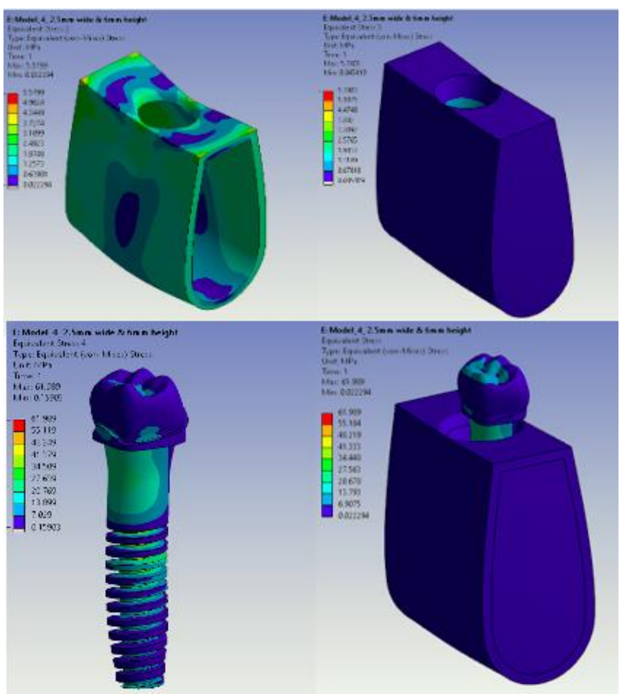

Figure 6: Stress distribution in (A) cortical bone and (B) cancellous bone, and strain distribution in (C) cortical bone and (D) cancellous bone in models with 6 mm bone loss.

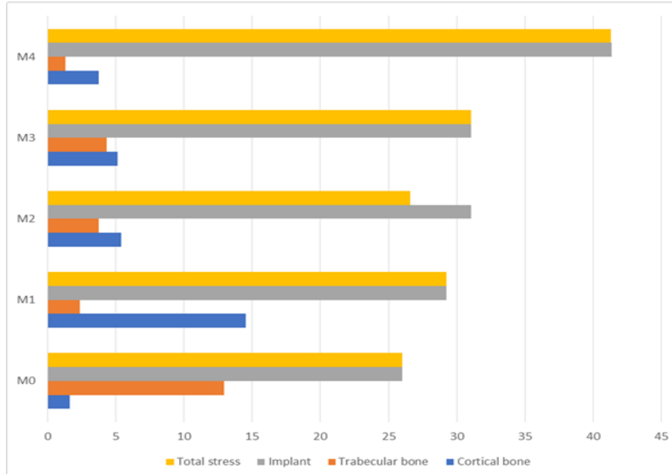

Figure 7: Von Mises stress (MPa) values with axial load (150 N) in (a) cortical bone, (b) trabecular bone, and (c) implant for no crestal bone loss (control group), 1 mm vertical and 0.5 mm horizontal crestal bone loss, 2 mm vertical and 1 mm horizontal crestal bone loss, 3 mm vertical and 1.5 mm horizontal crestal bone loss, and 6 mm vertical and 2.5 mm horizontal crestal bone loss.

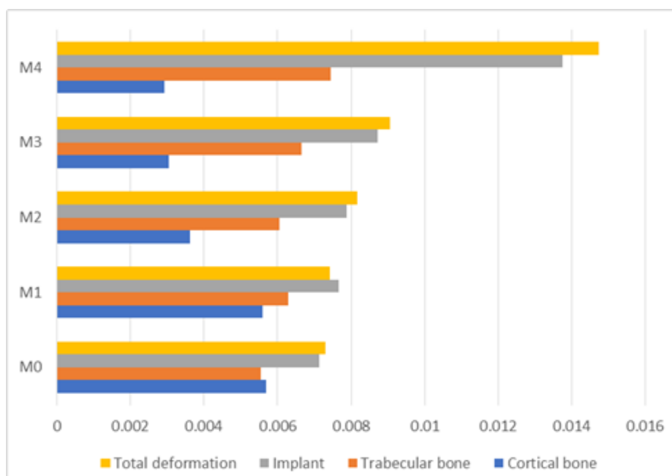

Figure 8: Von Mises strain values with axial load (150 N) in (a) cortical bone, (b) trabecular bone, and (c) implant for no crestal bone loss (control group), 1 mm vertical and 0.5 mm horizontal crestal bone loss, 2 mm vertical and 1 mm horizontal crestal bone loss, 3 mm vertical and 1.5 mm horizontal crestal bone loss, and 6 mm vertical and 2.5 mm horizontal crestal bone loss.