Ref: Ro J Stomatol. 2023;69(2)
DOI: 10.37897/RJS.2023.2.7

FEA on the biomechanical behavior of immediately loaded implants with different sizes

Raluca Monica Comaneanu[1,2], Teodora Mihali[1], Cherana Gioga[2], Anna Maria Pangica[2], Paula Perlea[3], Costin Coman[2], Violeta Hancu[2], Oana Botoaca[2], Monica Voiculeanu[3], Mihail Tarcolea[4,5]

[1]Doctoral School of Dental Medicine, "Titu Maiorescu" University of Bucharest, Romania
[2]Department of Dental Medicine Specialty Disciplines, Faculty of Dental Medicine, "Titu Maiorescu" University of Bucharest, Romania
[3]"Carol Davila" University of Medicine and Pharmacy, Bucharest, Romania
[4]BIOMAT Research Center, POLITEHNICA University of Bucharest, Romania
[5]Doctoral School of Materials Science and Engineering, POLITEHNICA University of Bucharest, Romania

ABSTRACT

Objectives. The purpose of this research was to study, in the case of immediate loading, the biomechanical effect produced by the length of the implants.

Material and method. The study material was a CBCT analysis performed on a patient from one dental office in Bucharest. An segment of edentulous mandibular bone was selected from the CBCT, which was processed with Mimics Innovation Suite, respectively Mimics and 3-matic. After processing the bone segment, two implants of the same manufacturer, with identical design, but different length – 10 and 13 mm respectively, were selected from the BIOMAT database. To simulate immediate loading, the bone-implant interface was not blocked and the mandible was defined with properties that characterize a bone with moderate density. A perpendicular masticatory force of 200N was applied to each of the two implants. The software ANSYS calculated the minimum, maximum values and their geometric means for the possible stresses produced on both the shorter implant (10 mm) and the longer implant (13 mm).

Results. In the case of short implants, higher average stresses develop along the entire length of the implant, towards the vestibular bone plate, while in the case of long implants the higher stress seems to be cantoned towards the apical side.

Conclusions. The present study shows that, in the case of immediate loading, the use of longer implants (13 mm) reduces by more than 50% the geometric mean of the stresses to which the bone-implant interface is subjected than in the case of the use of shorter implants (10 mm). In both types of implants, higher stresses occur at the level of the screw fixing the abutment in the implant.

Keywords: FEA, immediate loading, short implant, long implant

INTRODUCTION

In recent years, implantology [1-6] has become an extremely important branch of dentistry that has developed a lot. The short time between the surgical and prosthetic stages makes the major difference between immediate [7-9] and conventional loading [10,11]. Immediate loading is an excellent answer to the aesthetic and functional needs of patients, so the long-time frame provided by conventional protocols can be shortened to one hour after surgery. At the interface of some components of a mechanical system, micromovements can occur, resulting in the displacement of one of the component parts in relation to the other [12]. In the case of dental implantology, the phenomenon of micro-movement of the components that composed the mechanical system can be detected at the level of two interfaces, either at the connection of the abutment with the implant [13,14], or at the limit between the implant and the

Corresponding author:
Teodora Mihali
E-mail: teomihali@yahoo.com

Article History:
Received: 20 June 2023
Accepted: 27 June 2023

patient's bone [15]. Over time, multiple studies on the effect of micromovements at the level of the two interfaces have carried out, but for now there is no consensus regarding the phenomena produced exactly at these levels [12]. The micromovements produced at the border between the abutment and the implant lead to the formation of a microspace that will be colonized by bacteria and that will cause inflammation of the peri-implant tissues [16]. These micromovements will lead to the unscrewing of the abutment [17], affecting the performance of the prosthetic component [18,19]. Micromotion produced at this level is an engineering design issue that is the prerogative of implant manufacturers [12]. In contrast, micromovements at the bone-implant interface occur when loading a non-osseointegrated implant, as is the case with immediate loading [20]. Occlusal pressures lead to displacement of the implant in relation to the implant's alveolus [12]. Studies [20-26] have shown that a displacement of 50-150 μm produced during the period of bone healing can lead to fibrous encapsulation of the implant, endangering the long-term prognosis. Reducing the risk of fibrous encapsulation of the implant is solved by applying the protocol of late prosthetic loading of the implants [27]. The introduction of early and immediate loading protocols [20] must take into account this risk factor, represented by potential micromotion at the bone-implant interface [27,28]. Experimental approaches in this regard are limited by the difficulty of having available implants at various stages of osseointegration [23,29,30] but finite element analysis (FEA) are particularly useful for simulating micromotions and studying the mode of stress, tensions and deformations transmission when applying a force [21,22,31]. The purpose of this research was to study, in the case of immediate loading, the biomechanical effect produced by the length of the implants.

MATERIAL AND METHOD

The study was carried out according to a protocol approved by the Ethics Committee of the Faculty of Dental Medicine of the Titu Maiorescu University in Bucharest (no. 5/12.01.2017), respecting the Helsinki declaration and human rights, without harming the patients or the environment. The study material was a CBCT analysis performed on a patient from one dental office in Bucharest. The simulations were carried out with the support of the BIOMAT Research Center – Politehnica University of Bucharest. An edentulous mandibular bone segment was selected from the CBCT, which was processed with Mimics Innovation Suite, respectively Mimics and 3-matic. After processing the bone segment, two implants of the same manufacturer, with identical design, but different length – 10 and 13 mm respectively, were selected from the BIOMAT database. First the short implant and then the long implant were positioned and exported to NASTRAN format. NASTRAN is a finite element analysis (FEA) program that was originally developed for NASA in the late 1960s under United States government funding for the aerospace industry. The MacNeal-Schwendler Corporation (MSC) was one of the principal and original developers of the publicly available NASTRAN code [32,33]. NASTRAN source code is integrated in a number of different software packages, which are distributed by a range of companies [34]. This format is necessary to be able to transmit the geometrical bone-implant assembly to ANSYS for finite element analysis at masticatory forces. To simulate immediate loading, the bone-implant interface was not blocked and the mandible was defined with properties that characterize a bone with moderate density. A perpendicular masticatory force of 200N was applied to each of the two implants. The ANSYS software calculated the minimum values, maximum values and their geometric means for the possible stresses produced on both the shorter implant (10 mm) and the longer implant (13 mm).

RESULTS

The analyzed parameters varied for the two types of embankments, and some of them also varied in terms of distribution. The calculated results for the two types of implants are recorded in tables 1-2, and those parameters for which the distributions varied are illustrated comparatively in figures 1-6. In the case of short implants, higher average stresses develop along the entire length of the implant, towards the vestibular bone plate, while in the case of long implants the higher stress seems to be cantoned towards the apical side. In both types of implants, higher stresses also develop at the level of the screw fixing the abutment in the implant.

DISCUSSIONS

Since the experimental capabilities in implantology are greatly limited by the ethical aspects of research on human subjects, finite element analyses are useful procedures for understanding the micro-displacements that occur in oral implantology. For a relevant assessment in the field, we measured both the displacements of the implants and the bone, in contrast to other authors [23,35] who performed measurements at the level of photographs capturing the displacement of the implants to compare the effect of the occlusal stress of some provisional restorations on the implants' micromotion. The present study demonstrates that implant length has an important influence on the absolute values and mode of transmission of stresses, strains, and deformations at the bone level, with direct implica-

TABLE 1. Results for short implant (10 mm)

Object Name	Total Deformation [mm]	Directional Deformation X, [mm]	Directional Deformation Y, [mm]	Directional Deformation Z, [mm]	Equivalent Elastic Strain, [-]	Maximum Principal Elastic Strain, [-]	Minimum Principal Elastic Strain, [-]	Maximum Shear Elastic Strain, [-]	Normal Elastic Strain X, [-]	Normal Elastic Strain Y, [-]	Normal Elastic Strain Z, [-]	Shear Elastic Strain XY, [-]	Shear Elastic Strain YZ, [-]	Shear Elastic Strain XZ, [-]
Results														
Minimum	0	-7.83e-3	-2.01e-2	-0.143	0	-7.51e-5	-1.71e-2	0	-3.28e-3	-8.81e-3	-8.82e-3	-7.2e-3	-1.49e-2	-7.48e-3
Maximum	0.201	1.09e-2	0.17	1.e-2	1.44e-2	9.47e-3	2.18e-5	1.74e-2	1.65e-3	6.31e-3	5.4e-3	6.06e-3	1.07e-2	6.16e-3
Average	0.118	2.6e-3	8.69e-2	-7.32e-2	8.94e-4	4.33e-4	-6.2e-4	1.05e-3	1.75e-6	8.13e-5	-2.05e-4	-3.06e-5	-1.13e-4	-5.47e-5
Minimum On	Mandible				Implant	Mandible		Implant	Mandible					
Maximum On	Mandible		Implant	Mandible										

Object Name	Equivalent Stress, [MPa]	Maximum Principal Stress, [MPa]	Minimum Principal Stress, [MPa]	Maximum Shear Stress, [MPa]	Normal Stress X, [MPa]	Normal Stress Y, [MPa]	Normal Stress Z, [MPa]	Shear Stress XY, [MPa]	Shear Stress YZ, [MPa]	Shear Stress XZ, [MPa]
Minimum	-4,4e-3	-8,69e-3	-6,23e-3	2,08e-4	-38,6	-299	1,18e-4	-161	-104	-271
Maximum	8,32e-3	4,63e-3	6,48e-3	291	190	51,1	159	151	69,2	109
Average	8.4	2.84	-6.42	4.63	-0.427	-0.131	-3.43	-0.195	-0.907	-0.284
Minimum On	Implant									
Maximum On	Implant									

TABLE 2. Results for long implant (13 mm)

Object Name	Total Deformation [mm]	Directional Deformation X, [mm]	Directional Deformation Y, [mm]	Directional Deformation Z, [mm]	Equivalent Elastic Strain, [-]	Maximum Principal Elastic Strain, [-]	Minimum Principal Elastic Strain, [-]	Maximum Shear Elastic Strain, [-]	Normal Elastic Strain X, [-]	Normal Elastic Strain Y, [-]	Normal Elastic Strain Z, [-]	Shear Elastic Strain XY, [-]	Shear Elastic Strain YZ, [-]	Shear Elastic Strain XZ, [-]
Results														
Minimum	0	-6.62e-3	-4.11e-3	-7.93e-2	0	-7.82e-6	-1.58e-2	0	-1.97e-3	-1.82e-3	-1.22e-2	-4.57e-3	-7.55e-3	-4.57e-3
Maximum	0.144	5.9e-3	0.134	2.28e-2	1.61e-2	7.04e-3	1.36e-4	1.99e-2	2.06e-3	1.51e-3	6.77e-3	4.79e-3	3.25e-3	4.79e-3
Average	7.66e-2	-6.44e-4	6.69e-2	-3.1e-2	6.78e-4	3.32e-4	-5.03e-4	8.35e-4	1.76e-5	7.21e-5	-2.03e-4	-1.42e-5	-5.78e-5	-1.42e-5
Minimum On	Implant	Mandible			Implant	Mandible		Implant	Mandible					
Maximum On	Mandible		Implant	Mandible										

Object Name	Equivalent Stress, [MPa]	Maximum Principal Stress, [MPa]	Minimum Principal Stress, [MPa]	Maximum Shear Stress, [MPa]	Normal Stress X, [MPa]	Normal Stress Y, [MPa]	Normal Stress Z, [MPa]	Shear Stress XY, [MPa]	Shear Stress YZ, [MPa]	Shear Stress XZ, [MPa]
Minimum	0	-9.8	-58.6	0	-29.3	-45.4	-54.7	-21.7	-20.6	-28.5
Maximum	80.8	69.2	14.7	46.3	19.2	59.1	30.8	12.2	33.2	19.2
Average	4.26	0.953	-3.66	2.31	-0.264	-4.25e-2	-2.61	-8.22e-2	-0.406	-0.225
Minimum On	Implant									
Maximum On	Implant									

tions to produce osseointegration or fibrous encapsulation. Referring to other similar studies in the literature [20-26], the values calculated in the present study are low and do not exceed a threshold at which osseointegration could be endangered, but it is still remarkable that in the case of short implants, stresses and strains develop with double and even triple average values compared to the values calculated in the case of long implants.

CONCLUSIONS

1. Finite element analysis is a reliable tool that, although it involves additional time and the creation of a multidisciplinary team to work together to determine the optimal therapeutic solution for a given clinical situation, allows for the accurate determination of vulnerable areas, in which may produce biomechanical over stresses, with an impact on the osseointegration of immediately loaded implants. 2. At axial stresses of up to 200 N of the immediately loaded implants, excessive stresses and strains do not occur, which could jeopardize the achievement of osseointegration and the maintenance of long-term therapeutic success. 3. The present study shows that, in the case of immediate loading, the use of longer implants (13 mm) reduces by more than 50% the geometric mean of the stresses to which the bone-implant interface is subjected than in the case of the use of shorter implants (10 mm). 4. In both types of implants, higher stresses occur at the level of the screw fixing the abutment in the implant. 5. Regarding the stress transmitted to the bone, the use of shorter immediately loaded implants is associated with stressing the bone-implant interface along the entire length of the implant, towards the vestibule, and the use of longer immediately loaded implants is associated with higher stress on the mandibular bone especially at the apex of the implant.

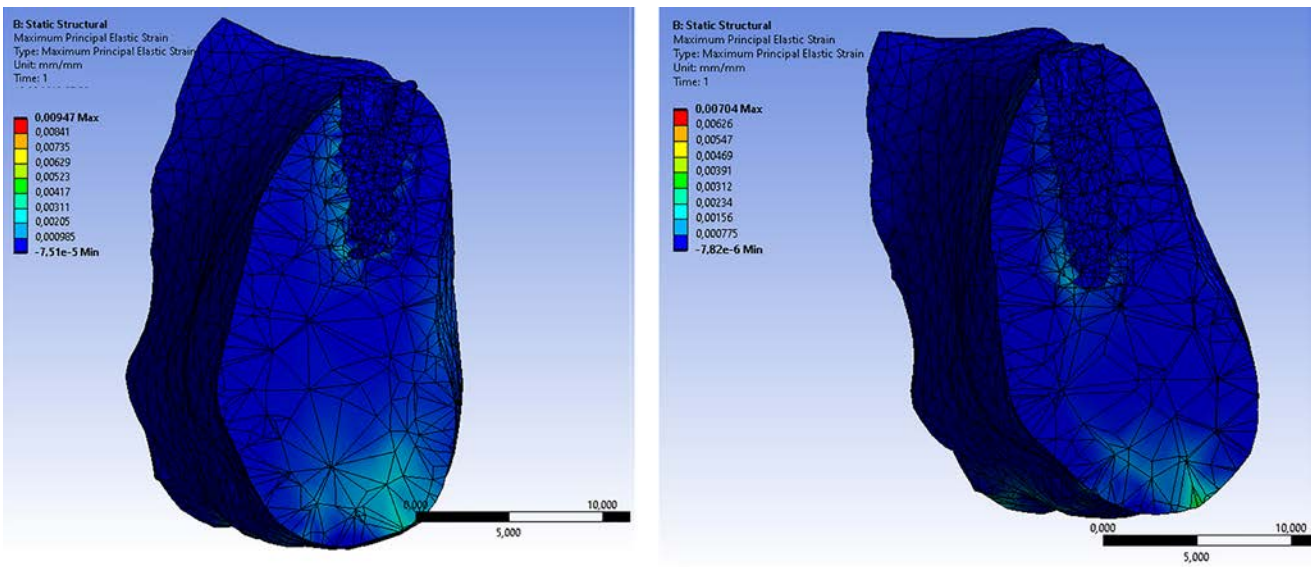

FIGURE 1. Maximum Principal Elastic Strain for short (left) and long implant (right)

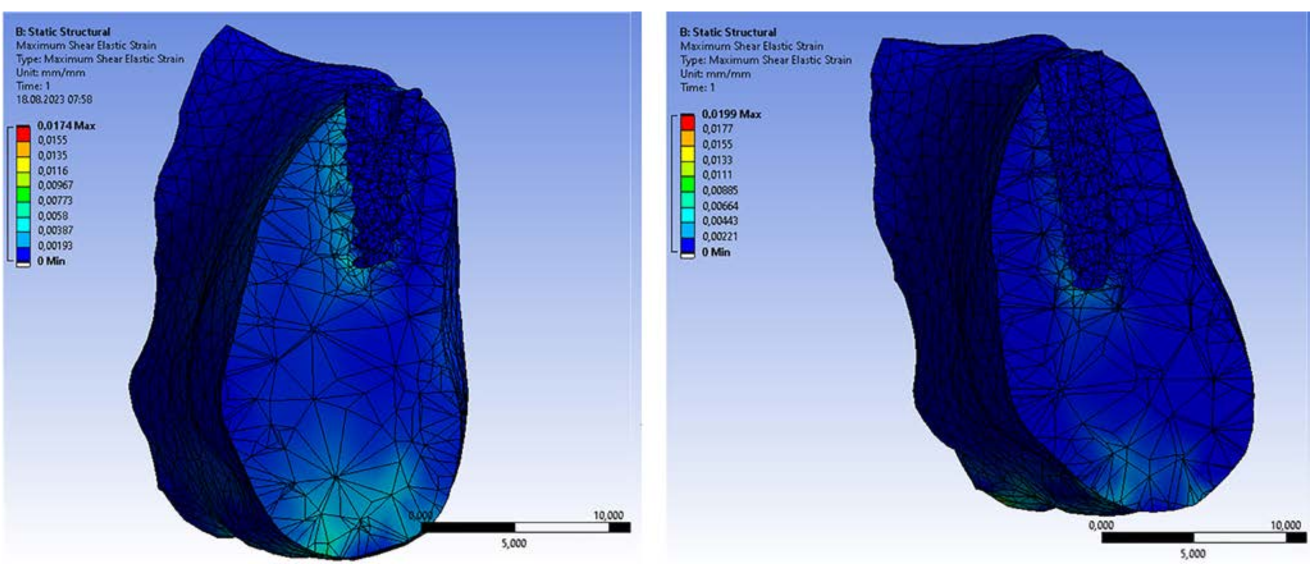

FIGURE 2. Maximum Shear Elastic Strain for short (left) and long implant (right)

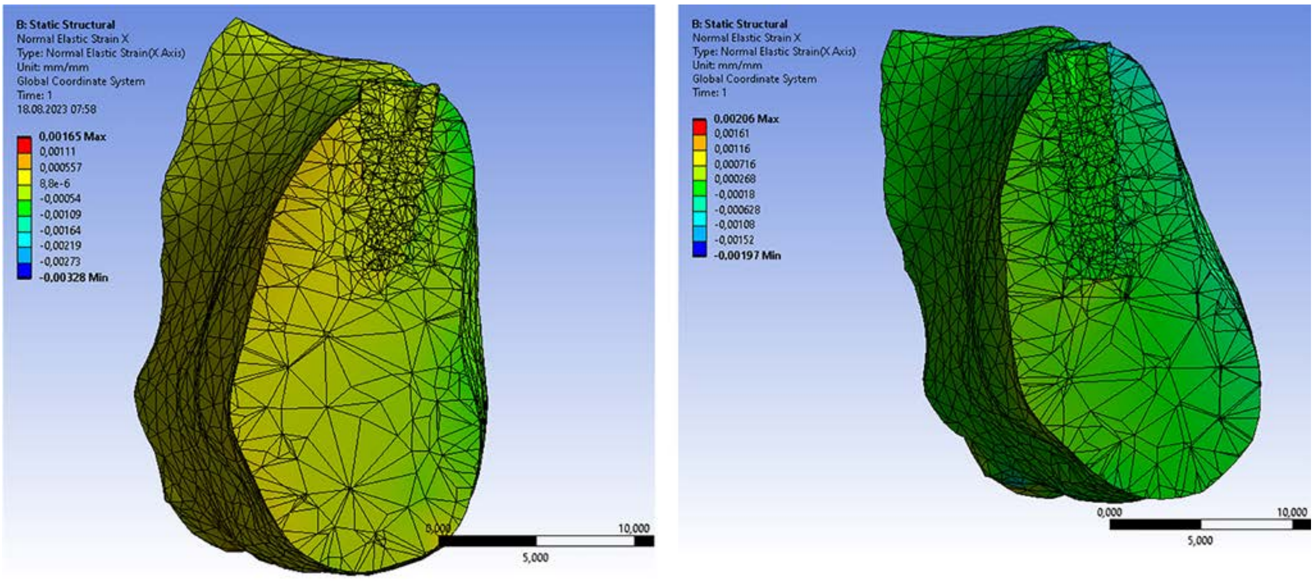

FIGURE 3. Normal Elastic Strain X for short (left) and long implant (right)

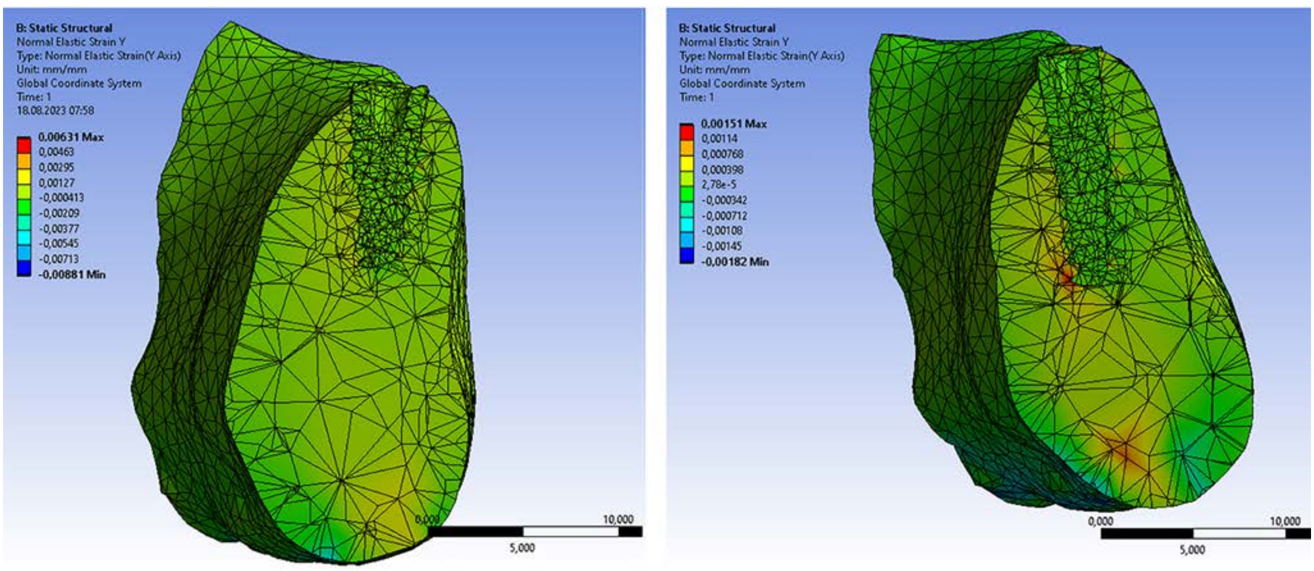

FIGURE 4. Normal Elastic Strain Y for short (left) and long implant (right)

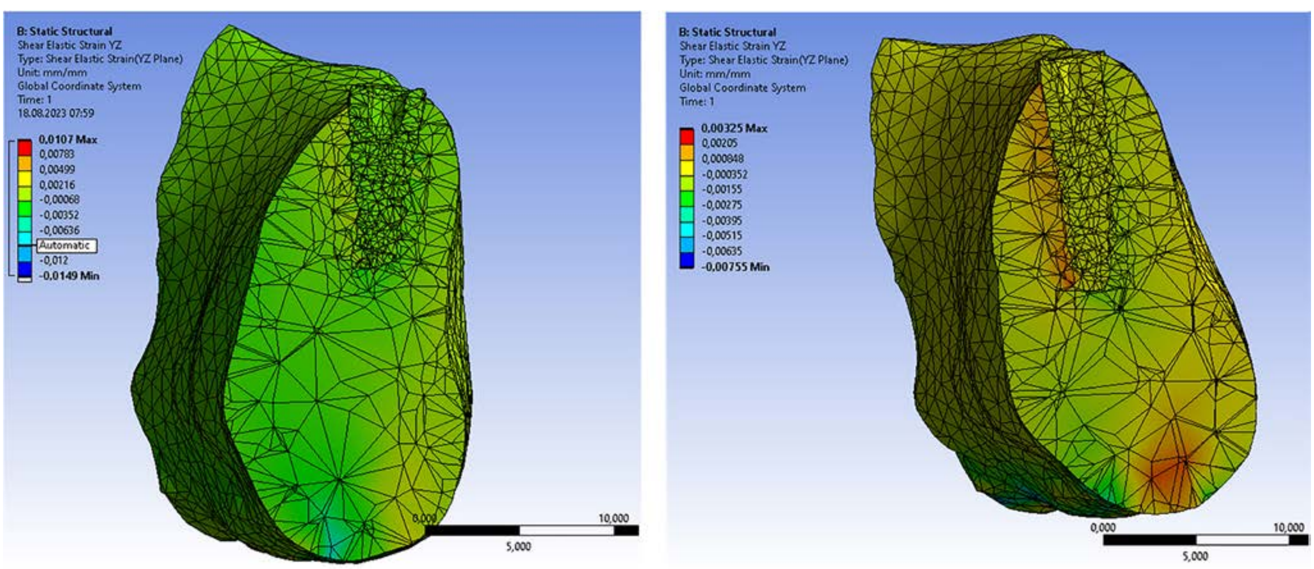

FIGURE 5. Shear Elastic Strain YZ for short (left) and long implant (right)

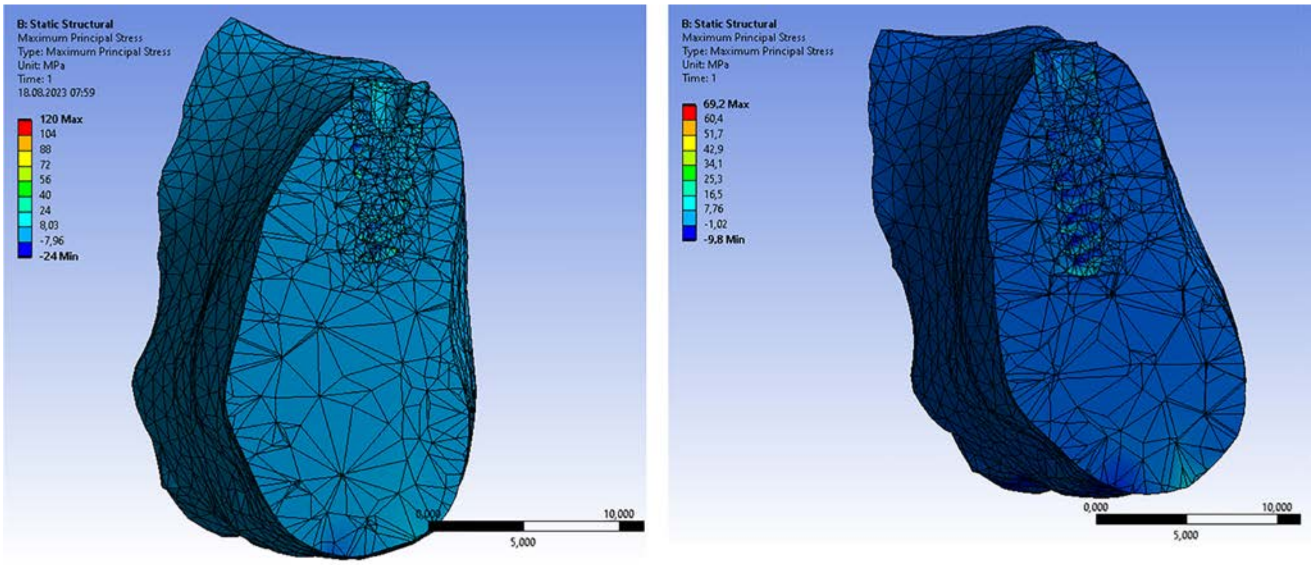

FIGURE 6. Maximum Principal Stress for short (left) and long implant (right)

Conflict of interest: none declared
Financial support: none declared

Acknowledgments: all authors contributed equally to the manuscript.

REFERENCES

1. Mohammad-Rahimi H, Motamedian SR, Pirayesh Z, Haiat A, Zahedrozegar S, Mahmoudinia E et al. Deep learning in periodontology and oral implantology: A scoping review. *J Periodontal Res.* 2022 Oct;57(5):942-951. doi: 10.1111/jre.13037
2. Gupta R, Gupta N, Weber, DDS KK. Dental Implants. 2023 Aug 8. In: StatPearls [Internet]. Treasure Island (FL): StatPearls Publishing; 2023 Jan–. PMID: 29262027.
3. Végh D, Bencze B, Banyai D, Vegh A, Rózsa N, Nagy Dobó C et al. Preoperative HbA1c and Blood Glucose Measurements in Diabetes Mellitus before Oral Surgery and Implantology Treatments. *Int J Environ Res Public Health.* 2023 Mar 8;20(6):4745. doi: 10.3390/ijerph20064745
4. Kihara H, Hatakeyama W, Kondo H, Yamamori T, Baba K. Current complications and issues of implant superstructure. *J Oral Sci.* 2022 Oct 1;64(4):257-262. doi: 10.2334/josnusd.21-0534
5. Salgado-Peralvo ÁO, Fernández-Cerero D, Garcia-Sanchez A, Kewalramani N, Velasco-Ortega E, Jiménez-Guerra Á et al. State of the Oral Implantology Practice in Spain during the COVID-19 Pandemic: A Cross-Sectional Survey. *Int J Environ Res Public Health.* 2023 Jan 18;20(3):1743. doi: 10.3390/ijerph20031743
6. Espinosa-Giménez J, Paredes-Gallardo V, Gómez-Adrián MD, Bellot-Arcís C, García-Sanz V. Scientific production of an oral implantology journal: a 5-year bibliometric study. Scientometrics. 2023;128(6):3535-3554. doi: 10.1007/s11192-023-04696-4
7. Pera F, Pesce P, Menini M, Fanelli F, Kim BC, Zhurakivska K et al. Immediate loading full-arch rehabilitation using transmucosal tissue-level implants with different variables associated: a one-year observational study. *Minerva Dent Oral Sci.* 2023 May 16. doi: 10.23736/S2724-6329.23.04782-4
8. Morris GA, Steinberg MJ, Drago C. Full arch immediate occlusal loading using site specific implants: A clinical series of 10 patients (13 arches). *J Prosthodont.* 2023 Mar;32(3):204-213. doi: 10.1111/jopr.13620
9. Mundt T, Heinemann F, Müller J, Schwahn C, Al Jaghsi A. Survival and stability of strategic mini-implants with immediate or delayed loading under removable partial dentures: a 3-year randomized controlled clinical trial. *Clin Oral Investig.* 2023 Apr;27(4):1767-1779. doi: 10.1007/s00784-022-04805-2
10. Pedrinaci I, Sun TC, Sanz-Alonso M, Sanz-Esporrin J, Hamilton A, Gallucci GO. Implant survival in the anterior mandible: A retrospective cohort study. *Clin Oral Implants Res.* 2023 May;34(5):463-474. doi: 10.1111/clr.14052
11. Gallucci GO, Hamilton A, Zhou W, Buser D, Chen S. Implant placement and loading protocols in partially edentulous patients: A systematic review. *Clin Oral Implants Res.* 2018 Oct;29 Suppl 16:106-134. doi: 10.1111/clr.13276
12. Winter W, Klein D, Karl M. Effect of model parameters on finite element analysis of micromotions in implant dentistry. *J Oral Implantol.* 2013 Feb;39(1):23-9. doi: 10.1563/AAID-JOI-D-11-00221
13. Meng JC, Everts JE, Qian F, Gratton DG. Influence of connection geometry on dynamic micromotion at the implant-abutment interface. *Int J Prosthodont.* 2007 Nov-Dec;20(6):623-5. PMID: 18069372.
14. Gratton DG, Aquilino SA, Stanford CM. Micromotion and dynamic fatigue properties of the dental implant-abutment interface. *J Prosthet Dent.* 2001 Jan;85(1):47-52. doi: 10.1067/mpr.2001.112796
15. Leucht P, Kim JB, Wazen R, Currey JA, Nanci A, Brunski JB et al. Effect of mechanical stimuli on skeletal regeneration around implants. *Bone.* 2007 Apr;40(4):919-30. doi: 10.1016/j.bone.2006.10.027
16. Steinebrunner L, Wolfart S, Bössmann K, Kern M. In vitro evaluation of bacterial leakage along the implant-abutment interface of different implant systems. *Int J Oral Maxillofac Implants.* 2005 Nov-Dec;20(6):875-81. PMID: 16392344.
17. Dixon DL, Breeding LC, Sadler JP, McKay ML. Comparison of screw loosening, rotation, and deflection among three implant designs. *J Prosthet Dent.* 1995 Sep;74(3):270-8. doi: 10.1016/s0022-3913(05)80134-9
18. Norton MR. Assessment of cold welding properties of the internal conical interface of two commercially available implant systems. *J Prosthet Dent.* 1999 Feb;81(2):159-66. doi: 10.1016/s0022-3913(99)70243-x
19. Norton MR. In vitro evaluation of the strength of the conical implant-to-abutment joint in two commercially available implant systems. *J Prosthet Dent.* 2000 May;83(5):567-71. doi: 10.1016/s0022-3913(00)70016-3
20. Romanos GE. Present status of immediate loading of oral implants. *J Oral Implantol.* 2004;30(3):189-97. doi: 10.1563/1548-1336(2004)30<189:PSOILO>2.0.CO;2
21. Udofia I, Liu F, Jin Z, Roberts P, Grigoris P. The initial stability and contact mechanics of a press-fit resurfacing arthroplasty of the hip. *J Bone Joint Surg Br.* 2007 Apr;89(4):549-56. doi: 10.1302/0301-620X.89B4.18055
22. Holmes DC, Loftus JT. Influence of bone quality on stress distribution for endosseous implants. *J Oral Implantol.* 1997;23(3):104-11.

23. Holst S, Geiselhoeringer H, Wichmann M, Holst AI. The effect of provisional restoration type on micromovement of implants. *J Prosthet Dent.* 2008 Sep;100(3):173-82. doi: 10.1016/S0022-3913(08)60176-6
24. Kawahara H, Kawahara D, Hayakawa M, Tamai Y, Kuremoto T, Matsuda S. Osseointegration under immediate loading: biomechanical stress-strain and bone formation-resorption. *Implant Dent.* 2003;12(1):61-8. doi: 10.1097/01.id.0000034394.75768.e3
25. Brunski JB. In vivo bone response to biomechanical loading at the bone/dental-implant interface. *Adv Dent Res.* 1999 Jun;13:99-119. doi: 10.1177/08959374990130012301
26. Szmukler-Moncler S, Salama H, Reingewirtz Y, Dubruille JH. Timing of loading and effect of micromotion on bone-dental implant interface: review of experimental literature. *J Biomed Mater Res.* 1998 Summer;43(2):192-203. doi: 10.1002/(sici)1097-4636(199822)43:2<192::aid-jbm14>3.0.co;2-k
27. Szmukler-Moncler S, Piattelli A, Favero GA, Dubruille JH. Considerations preliminary to the application of early and immediate loading protocols in dental implantology. *Clin Oral Implants Res.* 2000 Feb;11(1):12-25. doi: 10.1034/j.1600-0501.2000.011001012.x
28. Trisi P, Perfetti G, Baldoni E, Berardi D, Colagiovanni M, Scogna G. Implant micromotion is related to peak insertion torque and bone density. *Clin Oral Implants Res.* 2009 May;20(5):467-71. doi: 10.1111/j.1600-0501.2008.01679.x
29. Engelke W, Decco OA, Rau MJ, Massoni MC, Schwarzwäller W. In vitro evaluation of horizontal implant micromovement in bone specimen with contact endoscopy. *Implant Dent.* 2004 Mar;13(1):88-94. doi: 10.1097/01.id.0000116457.03989.01
30. Bühler DW, Oxland TR, Nolte LP. Design and evaluation of a device for measuring three-dimensional micromotions of press-fit femoral stem prostheses. *Med Eng Phys.* 1997 Mar;19(2):187-99. doi: 10.1016/s1350-4533(96)00060-4
31. Kao HC, Gung YW, Chung TF, Hsu ML. The influence of abutment angulation on micromotion level for immediately loaded dental implants: a 3-D finite element analysis. *Int J Oral Maxillofac Implants.* 2008 Jul-Aug;23(4):623-30. PMID: 18807557.
32. NASA Releases Classic Software To Public Domain on newsbytes.com by Susan M (25 Oct 2001)
33. NTTC, OSC Celebrate Space Agency's Birthday, Launch "NASA CLASSICS" Software Apps to Commercial Markets Archived 2016-05-16 at the Wayback Machine on openchannelsoftware.com (2001)
34. https://en.wikipedia.org/wiki/Nastran#cite_note-source available1-1
35. Goellner M, Schmitt J, Karl M, Wichmann M, Holst S. The effect of axial and oblique loading on the micromovement of dental implants. *Int J Oral Maxillofac Implants.* 2011 Mar-Apr;26(2):257-64. PMID: 21483878.