POLITECNICO DI TORINO
Repository ISTITUZIONALE

Evaluation of Tension and Deformation in a Mandibular Toronto Bridge Anchored on Three Fixtures Using Different Framework Materials, Abutment Systems, and Loading Conditions:

Original
Evaluation of Tension and Deformation in a Mandibular Toronto Bridge Anchored on Three Fixtures Using Different Framework Materials, Abutment Systems, and Loading Conditions: A FEM Analysis / Grande, F., Mario Cesare, P., Mochi Zamperoli, E., Martina Gianoli, C., Mollica, F., Catapano, S.. - In: EUROPEAN JOURNAL OF DENTISTRY. - ISSN 1305-7456. - (2023). [10.1055/s-0042-1758785]

Availability:
This version is available at: 11583/2983331 since: 2023-10-25T15:56:06Z

Publisher:
Thieme

Published
DOI:10.1055/s-0042-1758785

Terms of use:

This article is made available under terms and conditions as specified in the corresponding bibliographic description in the repository

Publisher copyright

(Article begins on next page)

29 November 2026

Article published online: 2023-01-25

Evaluation of Tension and Deformation in a Mandibular Toronto Bridge Anchored on Three Fixtures Using Different Framework Materials, Abutment Systems, and Loading Conditions: A FEM Analysis

Francesco Grande[1] Pozzan Mario Cesare[2] Edoardo Mochi Zamperoli[2] Camilla Martina Gianoli[3] Francesco Mollica[4] Santo Catapano[2]

[1] Department of Mechanical and Aerospace Engineering, Politecnico di Torino, Turin, Italy
[2] Department of Prosthodontics, University of Ferrara, Ferrara, Italy
[3] CIR Dental School Department of Surgical Sciences, University of Turin, Torino, Italy
[4] Department of Engineering, University of Ferrara, Ferrara, Italy

Address for correspondence Francesco Grande, DDS, MSc, PhD, Department of Mechanical and Aerospace Engineering, Politecnico di Torino, Via Nizza, 230, 10126 Torino, Italy (e-mail: francesco.grande@polito.it).

Eur J Dent

Abstract

Objective The aim of this study was to investigate by finite element method analysis the behaviour of a three-implant mandible Toronto framework made by three different materials, with two abutment systems and two loading conditions.

Materials and Methods Three implants were virtually inserted in a mandible model in positions 3.6, 4.1, and 4.6. Three prosthetic framework bars with the same design and dimension (4.8 × 5.5 mm) were projected. The variables introduced in the computer model were the framework materials (glass fiber reinforced resin, Co-Cr, TiAl6V4), the abutment systems (Multi-Unit-Abutment [MUA]/OT-Bridge), and the loading conditions (500 N vertical load on all the framework area and 400 N on a 7-mm distal cantilever). The computer was programmed with physical properties of the materials as derived from the literature. Maximum tension and deformation values for each variable were registered at framework, screws, and abutment level and then compared.

Results Metal frameworks Cr-Co and TiAl6V4 resulted in lower deformation than glass fiber-reinforced resin frameworks while presenting higher tension values. The OT-Bridge exhibited lower maximum tension and deformation values than the MUA system. The first loading condition reached higher tension and deformation values than the second and it resulted in more uniformly distributed load on all the framework area, especially with the OT-Bridge system.

Conclusion More rigid materials and OT-Bridge system decrease the deformation on the prosthetic components. Tension stresses are more uniformly distributed with glass fiber-reinforced resin, in the OT-Bridge system and avoiding cantilever loading.

Keyword
- All-on-Three
- implant
- prosthesis
- FEM analysis
- OT-Bridge
- MUA

DOI https://doi.org/10.1055/s-0042-1758785.
ISSN 1305-7456.

© 2023. The Author(s).
This is an open access article published by Thieme under the terms of the Creative Commons Attribution License, permitting unrestricted use, distribution, and reproduction so long as the original work is properly cited. (https://creativecommons.org/licenses/by/4.0/)

Thieme Medical and Scientific Publishers Pvt. Ltd., A-12, 2nd Floor, Sector 2, Noida-201301 UP, India

Introduction

Nowadays, one of the main indications for the rehabilitation of edentulous patients, even with extensive bone atrophy, is represented by fixed implant prosthesis.[1–3] Depending on the quality and quantity of residual bone, the level of atrophy, and nerves positions, several implant rehabilitations can be performed.[4–7] Due to anatomical risk, the presence of the tongue, and the low quantity of keratinized tissue, the full-arch rehabilitation of the mandible represents a challenging procedure for dental surgeons. However, the arch described by the mandible is shorter than that of the upper arch, allowing the rehabilitation of a fixed implant prosthesis with four or also three implants. The All-On-Four technique, initially proposed by Maló et al[8] is nowadays used by several clinicians.[9–11] Different connection systems between prosthetic framework and implant fixtures in screw-retained rehabilitation are today available. For full-arch rehabilitations, the most used is the Multi-Unit-Abutment (MUA) system, available in a variety of size and angulations to achieve a passive prosthetic fit even in case of implant disparallelism.[7,12–14]

A valid alternative to MUA is represented by the OT-Bridge system (Rhein 83 S.R.L., Bologna, Italy), recently introduced in the market and also investigated in scientific studies.[15–17] It consists of a low-profile attachment (OT-Equator), a peculiar cylindrical abutment with an "Extragrade" region that houses an interchangeable acetal ring (Seeger ring), allowing a retention with the OT-Equator even in the absence of the tightening screw.[16] The OT-Equator attachment has been initially ideated and used only for overdenture, demonstrating a long-term surveillance on these types of rehabilitation.[18–21] Its use in combination with the Extragrade abutment allows the realization of fixed prosthesis also on tilted implants with several degree of divergence. Some studies comparing MUA and OT-Bridge systems has been conducted.[15,16] In all of these, an All-On-Four model was used to evaluate differences between the two systems in terms of preload loss. The OT-Bridge system was tested also without one or two screws to understand the possible clinical implication of avoiding the screw insertion. No significant loss of screw tightening force was detected in comparison to the MUA system after approximately 1-year of cyclic loadings and the OT-Bridge system performed well even in absence of one or two prosthetic screws. In a multicenter study with a 1-year evaluation period, the OT-Bridge system showed successful results when used to support maxillary fixed dental prosthesis delivered on four to six implants.[21]

In the past few years, another prosthetic alternative to All-On-Four has emerged: the All-On-Three technique.[22–25] This type of rehabilitation, specifically of the mandible, is gaining ground because of its reduced invasiveness, safety, and predictable results in the short-medium term.[8,25,26] However, the connection system, the loading conditions, and the composition of the framework could play an important role in preventing or favoring mechanical complications such as fractures, deformation of the frameworks, chipping, and wear of the ceramic coating.[27] Then, testing different framework materials and abutment system under different loading conditions is necessary to understand the behaviour of this possible implant-prosthetic rehabilitation.

To the best of our knowledge, there are no studies in literature comparing different framework materials and loading conditions with MUA and OT-Bridge system in an All-On-Three. Therefore, the aim of this study was to compare the behavior of dimensionally equal All-On-Three frameworks by finite element method (FEM) analysis in two loading conditions using two different abutment systems.

Materials and Methods

An epoxy resin model of the mandible was initially scanned by a high precision lab scanner (Optical RevEng, Open technologies S.R.L., Brescia, Italy) to obtain an STL file of the model. The mandibular geometry was simplified as a rectangular circular object by progressively reducing the number of meshes, using a three-dimensional (3D) mesh processing open-source software program (MeshLab, ISTI, Pisa, Italy).

Three implants (Nobel Parallel, Nobel Biocare, Kloten, Switzerland) were virtually inserted in the mandible, parallel to each other and perpendicular to the occlusal plane: one implant (3.75×10 mm) was placed near the mandibular symphysis (4.1 position) and two (4.3×10 mm) were positioned at the first left and right molars (3.6 and 4.6). Soft tissues were not considered.

Then, using an appropriate software program (SolidWorks 2018, Dassault Systèmes SolidWorks Corporation, Vélizy-Villacoublay, France), a prosthetic framework connecting the three implants was designed. The framework was provided of a rectangular geometry bar with a constant section of 4.8×5.5 mm. Three frameworks with the same design and geometry but different materials were obtained using (►**Table 1**):

1. Glass fiber-reinforced resin (Trilor Arch, Bioloren S.R.L., Saronno, Italy).
2. Cobalt-chromium (Co-Cr) (Magnum Lucens, Mesa Italia S. R.L., Travagliato, Italy).
3. Titanium alloy (Ti6Al4V, Arcam AB, Mölndal, Sweden).

For each material, two frameworks were created: one with the MUA system and the other with the OT-Bridge system. As a result, the following six models were virtually generated and tested:

1. Model with glass fiber-reinforced resin framework bar and the MUA system (M1).
2. Model with Co-Cr framework bar and the MUA system (M2).
3. Model with titanium alloy framework bar and the MUA system (M3).
4. Model with glass fiber-reinforced resin framework bar and the OT-Bridge system (M4).
5. Model with Co-Cr framework bar and the OT-Bridge system (M5).

Table 1 Mechanical characteristics of the materials used

	Materials' type	Materials	Young's modulus	Poisson's ratio
			E	v
			[GPa]	[-]
Cortical bone without cancellous	Linear isotropic elastic	Bone	12.5	0.30
MUA 618 42		Ti Gr5 ELI	105	0.34
Seeger 618 08		POM Kepital F30-03 03	3	0.44
OT-E Profile 113 35		Ti Gr5 ELI	105	0.34
Reinforced resin framework		Trilor Arch Bioloren	26	0.4
Co-Cr framework		Magnum Lucens	194	0.3
TiAl6V4 framework		TiAl6V4	105	0.34

Abbreviations: Co-Cr, cobalt-chromium; MUA, Multi-Unit-Abutment.

6. Model with titanium alloy framework bar and the OT-Bridge system (M6).

A FEM analysis for all the frameworks, using the ANSYS software (Ansys, Inc., Canonsburg, Pennsylvania, United States), was carried out. A 3D linear static parametric simulation was developed, considering the ratio (stress and strain) between bone and prosthetic components, and implants and OT-Equator attachments. Two different loading conditions were applied for each FEM:

- Perpendicular load of 500 N applied on the framework area between implants 4.1 and 3.6 (first loading condition) (►**Fig. 1**).
- Perpendicular load of 400 N applied on a 7-mm distal cantilever to 4.6, to generate a bending moment of the prosthetic framework (second loading condition) (►**Fig. 2**).

Both in the first and second loading conditions, the maximum values were recorded in terms of tension (MPa) and deformation (mm) in the axial direction at framework, screw, and abutment level. The mechanical behavior of the different frameworks was compared as the connection/abutment system changes.

The study was carried out with the hypotheses that linear elastic and isotropic materials, subjected to a tension, undergo an elastic deformation proportional to the tension itself according to a proportional factor, the Young's modulus. In the program fixed conditions were established in terms of linear elastic and isotropic material deformation. For the elasticity, the materials were subjected to a proportional deformation according to the Young's modulus of the material. It was also fixed that the material had the same mechanical and thermal properties in all directions (isotropy).

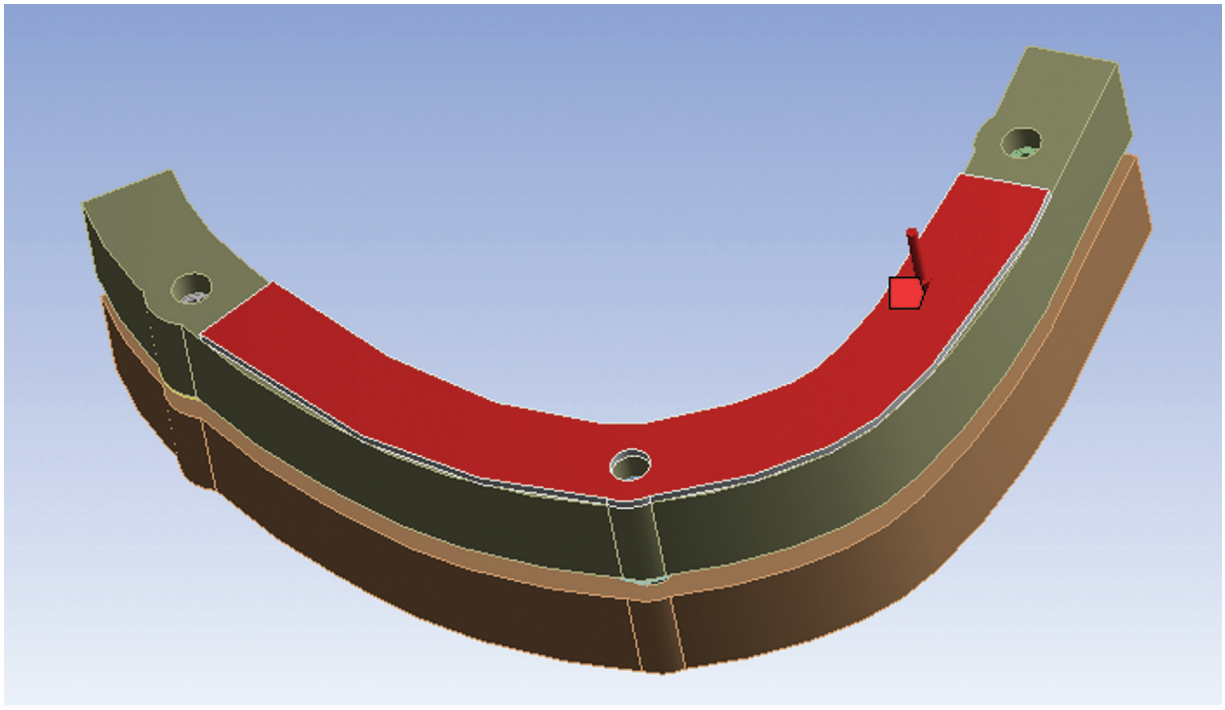

Fig. 1 First loading condition: application of a 500 N perpendicular load on the framework area between implants in 4.1 and 3.6 positions.

 © 2023. The Author(s).

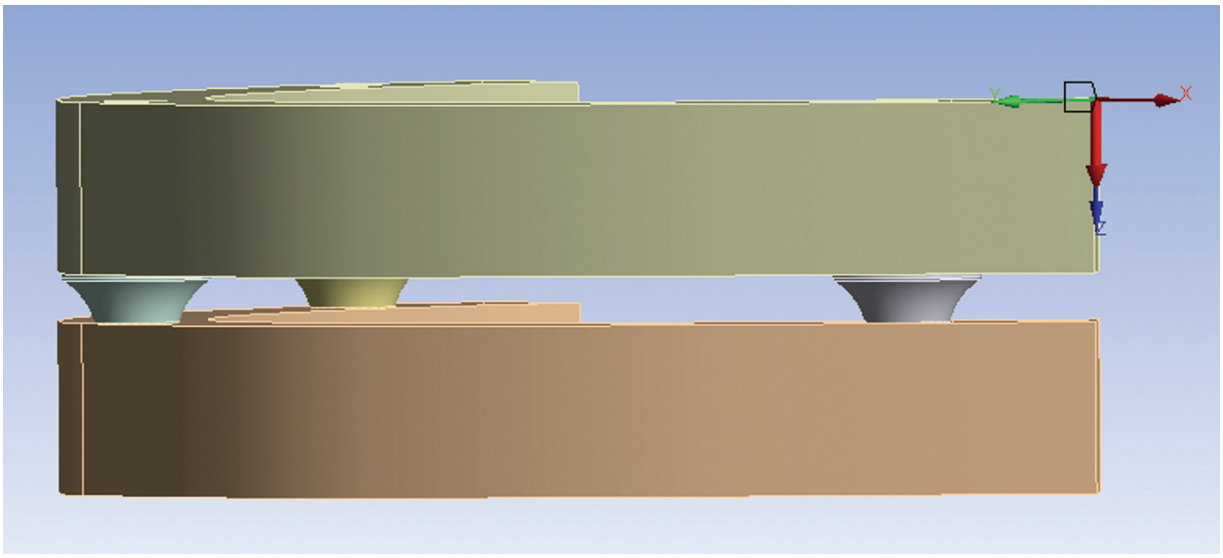

Fig. 2 Second loading condition: application of a 400 N perpendicular load on a 7-mm distal cantilever to 4.6 position.

Results

Results are summarized in ►**Tables 2–5**. The incidence of each variable on tension and deformation stresses at framework, screws, and abutment level was analyzed by matching the different results in several ways. Bar graphs of each comparison are attached as ►**Supplementary File.**

Materials

Regarding materials in the first loading condition, glass fiber-reinforced resin with Co-Cr and titanium decreased, respectively, of 70 and 40% the maximum stress tension of the framework using OT-Bridge (M4, M5, M6). When the distal cantilever is loaded (second loading condition), the same material had up to 63% less of maximum tension values

Table 2 Tensions values ([Mpa] σeq,vm) expressed in the first loading condition for each abutment system and framework material at framework, screw, and abutment level

	Abt system	Framework		Screws		Abt	
		Value (max)	Area	Value (max)	Area	Value (max)	Area
Resin	MUA (M1)	800	3.6, 4.1, 4.6	500	3.6 thread	650	3.6, 4.6 Cone bone seat
	OTP (M4)	200	3.6, 4.6	300	3.6, 4.6 thread	650	3.6, 4.6 Ot_eq and abt
Cr-Co	MUA (M2)	800	3.6, 4.1, 4.6	650	3.6 thread	680	3.6, 4.6 Cone bone seat
	OTP (M5)	650	3.6, 4.6	400	3.6, 4.6 thread	500	3.6, 4.6 Ot_eq and abt
TiAl6V4	MUA (M3)	800	3.6, 4.1, 4.6	650	3.6 thread	680	3.6, 4.6 Cone bone seat
	OTP (M6)	500	(3.6, 4.6	400	3.6, 4.6 thread and head	600	3.6, 4.6 Ot_eq and abt

Abbreviations: Abt, abutment; Cr-Co, chromium-cobalt; MUA, Multi-Unit-Abutment.

Table 3 Deformation values (mm) in the axial direction (*z*-axis) expressed in the first loading condition for each abutment system and framework material at framework, screw, and abutment level

	Abt system	Framework		Screws		Abt	
		Value (max)	Area	Value (max)	Area	Value (max)	Area
Resin	MUA (M1)	1.05	4.1	0.98	4.1	1.04	4.1
	OTP (M4)	0.9	4.1	0.88	4.1	0.92	4.1
Cr-Co	MUA (M2)	0.97	4.1	0.91	4.1	0.97	4.1
	OTP (M5)	0.88	4.1	0.83	4.1	0.87	4.1
TiAl6V4	MUA (M3)	0.99	4.1	0.93	4.1	0.99	4.1
	OTP (M6)	0.89	4.1	0.85	4.1	0.88	4.1

Abbreviations: Abt, abutment; Cr-Co, chromium-cobalt; MUA, Multi-Unit-Abutment.

 © 2023. The Author(s).

Table 4 Tensions values ([Mpa] σeq,vm) expressed in the second loading condition for each abutment system and framework material at framework, screw, and abutment level

	Abt system	Framework		Screws		Abt	
		Value (max)	Area	Value (max)	Area	Value (max)	Area
Resin	MUA (M1)	300	3.6	400	3.6 thread	650	3.6 Cone bone seat
	OTP (M4)	200	3.6	200	3.6 thread	650	3.6 Ot_eq
Cr-Co	MUA (M2)	800	3.6	400	3.6 start thread	650	3.6, 4.6 Cone bone seat
	OTP (M5)	300	3.6	170	3.6, 4.6 thread	600	3.6 Ot_eq
TiAl6V4	MUA (M3)	800	3.6	400	3.6 start thread	450	3.6 Cone bone seat
	OTP (M6)	300	3.6	170	3.6 thread		3.6 Ot_eq

Abbreviations: Abt, abutment; Cr-Co, chromium-cobalt; MUA, Multi-Unit-Abutment.

Table 5 Deformation values (mm) in the axial direction (*z*-axis) expressed in the first loading condition for each abutment system and framework material at framework, screw, and abutment level

	Abt system	Framework		Screws		Abt	
		Value (max)	Area	Value (max)	Area	Value (max)	Area
Resin	MUA (M1)	0.21	4.1	0.19	4.1	0.2	4.1
	OTP (M4)	0.18	4.1	0.16	4.1	0.17	4.1
Cr-Co	MUA (M2)	0.19	4.1	0.18	4.1	0.19	4.1
	OTP (M5)	0.17	4.1	0.16	4.1	0.17	4.1
TiAl6V4	MUA (M3)	0.2	4.1	0.18	4.1	0.2	4.1
	OTP (M6)	0.17	4.1	0.16	4.1	0.17	4.1

Abbreviations: Abt, abutment; Cr-Co, chromium-cobalt; MUA, Multi-Unit-Abutment.

compared to Co-Cr and titanium material in the MUA system (M1, M2, M3). Screws and abutment tension was not so affected by framework material.

Instead, deformation occurred for all the prosthetic components in all models in the range of 0.16 to 0.21 mm and resulted always higher for glass fiber-reinforced resin than metal frameworks.

Abutment System

In most of the cases, changing the connection type from MUA to OT-Bridge reduced tension values. Notable differences were observed in M1 versus M4 (800 vs. 200 MPa) and with Co-Cr and titanium at framework level applying the second loading condition (decrease of 37.5%). Screw tensions comparing the models showed a decrease from 40% in the first loading condition to 67.5% in the second loading condition. At abutment level, changing MUA with OT-Bridge slightly decreased the tension values only with Co-Cr (M2 vs. M5) especially in the first loading condition; a raise of 25% was observed with titanium (M3 vs. M6) in the second loading condition and was the only case in which tension values increased when passing from MUA to OT-Bridge. OT-Bridge showed a larger distribution of tension stresses across the framework, reducing their intensification in small areas for both the loading conditions.

Changing abutment system slightly influenced the deformation level of the different prosthetic components. A mild decrease of deformation values was observed when using OT-Bridge instead of MUA; the maximum value of difference (0.15 mm) was reached at framework level with M1 versus M4 in the first loading condition.

Loading Conditions

In all the models tested, the first loading condition reached higher tension stress and deformation values than the second loading condition. By passing from the first to the second loading condition, tension values decreased, in some cases, up to 62,5% at abutment (M1) and screw (M5, M6) level. Also, the deformation of the framework in axial direction (*z*-axis) decreased by about 80% in the second loading condition for all the materials and in all the components. However, the deformation of the framework bar was less uniformly distributed when the load is applied to the distal cantilever, resulting in higher deformation near the closest abutment similarly to tension distribution. In addition, in the first loading condition the anterior area of the framework reached maximum deformation while the distal portion had the lowest; changing loading set inversed the deformed location.

Discussion

Full-arch implant prosthesis must be planned and fabricated considering the distribution of forces on implant

components. Materials and abutment system affected the survival rate of implants, prosthesis, and the onset of mechanical complications. Despite all its inherent limitations,[28] FEM analysis represents a valid tool for studying the behaviour of implant-prosthetic components with different configurations, giving initial evaluation on the feasibility of a rehabilitation.[29]

The purpose of this FEM was to evaluate the mechanical behavior of a fixed prosthesis anchored on three implants using different materials for the framework bar, different connection system, and applying two different loading conditions to simulate occlusion. A mandibular model with all cortical bone and without cancellous was projected to maximize stresses at implant-prosthetic components, simulating the worst case scenario.[30] Perfect passivity between the components was assumed to avoid the appearance of internal tensions that may confound the analysis.

Materials

Co-Cr and titanium alloy frameworks generate greater tensions that were largely distributed, involving less framework deformation. Oppositely, despite the lower tensions, the glass fiber-reinforced resin material tends to concentrate them in a smaller surface, thus exposing the bar to greater deformations. This behaviour could be explained because of the material properties and to the rigidity provided by metal alloy. On the contrary, the lower Young's modulus of resin base framework may lead to a greater absorption of the load in the area of application without any or little tension distribution.

It is important to also consider the mechanical resistance of these materials, when planning a framework, to prevent mechanical complications such as chipping, fractures, and screw loosening under masticatory loads. Because of the lower rigidity and higher shock absorbance concentration of glass fiber-reinforced resin compared to metal alloys frameworks, it is important to plan a proper framework dimension when choosing this material. In addition, it is important to correctly select the material in relation to the clinical case. A higher framework resistance could be preferable in patients with higher masticatory forces and smaller loading distribution. Furthermore, for definitive restorations with ceramic coatings, it may be recommended to select a framework material that does not expose the bar to deformations in order to reduce chipping and fracture risks. Proper framework design is necessary in relation to the specific clinical case, number and position of implants, and to the material used.

Abutment

More concentrated local tensions were recorded and observed with the MUA system. Results proved that OT-Bridge distributes the acting tensions more uniformly, reducing their intensification for both the loading conditions. This could be due to the OT-Equator structural configuration which seems to collect the strength over the head of the retainer and not only in a single point[31] (►**Figs. 3** and **4**).

Another important result is that higher tensions and deformation were reached by MUA at all levels. This phenomenon could be described by the low profile and overall smaller size of the OT-Equator attachment which provides the framework of a greater dimensions and consequently greater mechanical properties. In addition, it is possible that in the OT-Bridge system, a portion of stress is transmitted to the Seeger ring which provides the interlocking connection between the implant and the prosthesis. Then, if an amount

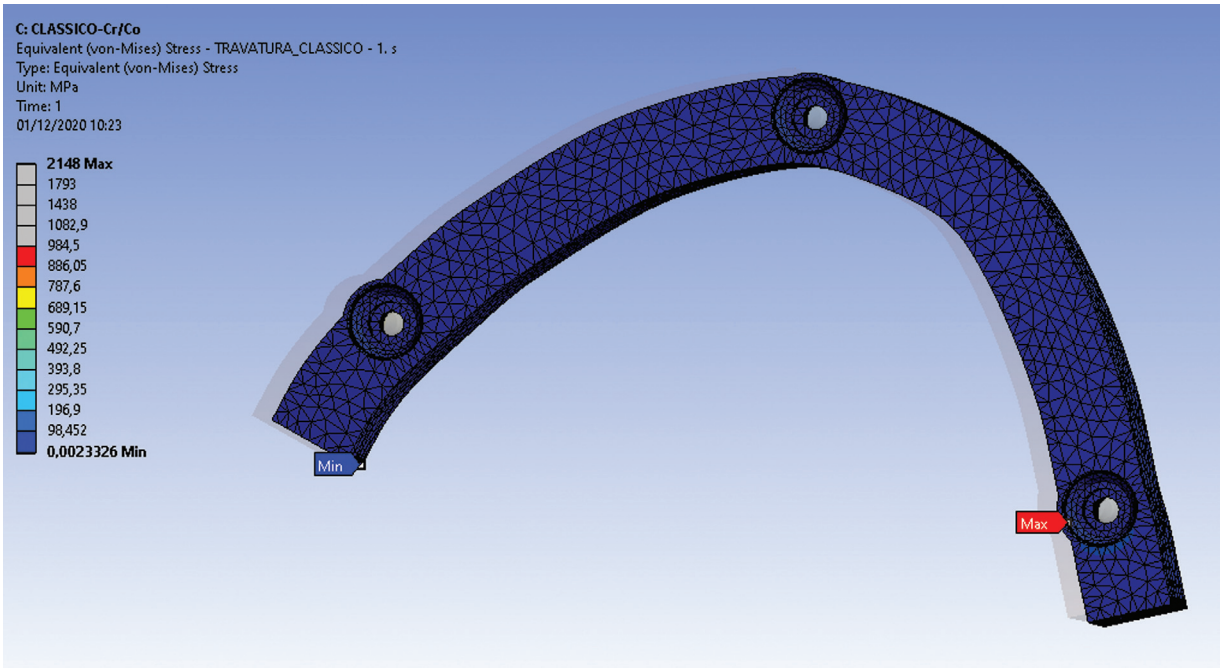

Fig. 3 Tension distribution at framework area of M2 (cobalt-chromium framework bar and Multi-Unit-Abutment [MUA] system) in the second loading condition. Tension values are expressed by a colorimetric scale. The location of minimum and maximum values are indicated.

 © 2023. The Author(s).

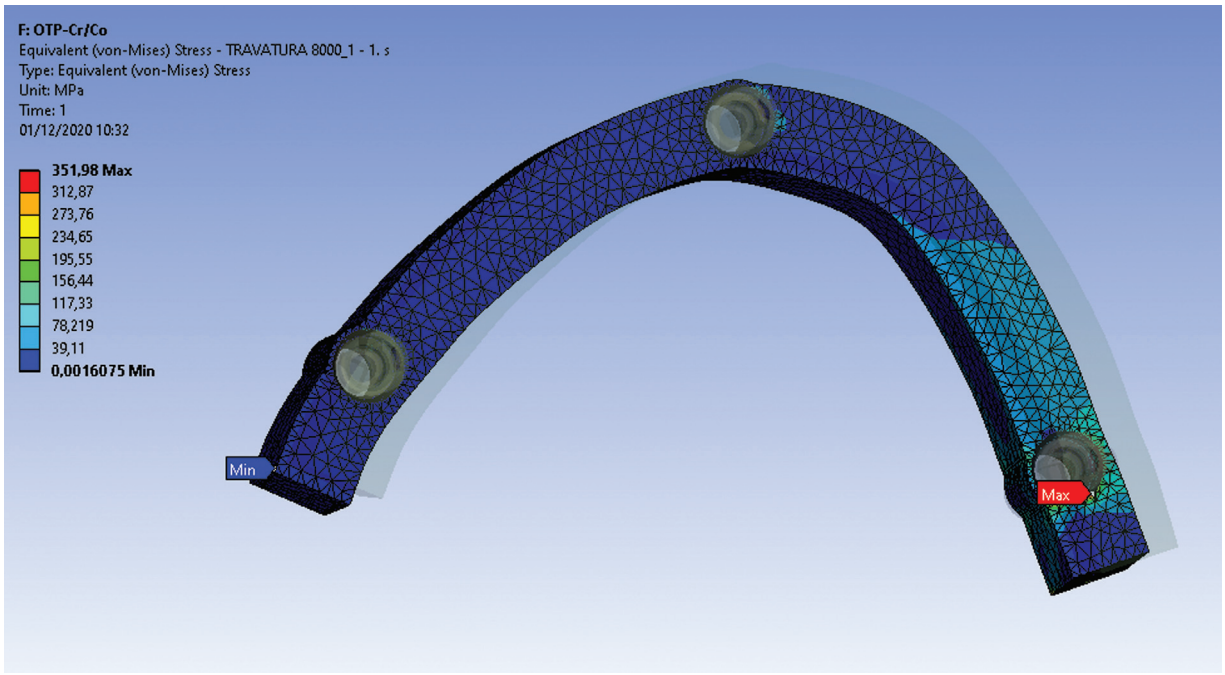

Fig. 4 Tension distribution at framework area of M4 (glass fiber-reinforced resin framework bar and OT-Bridge system) in the second loading condition. Tension values are expressed by a colorimetric scale. The location of minimum and maximum values are indicated.

of energy is dissipated in this way, especially in case of distal cantilever loading, a reduction of the transmitted energy happens, decreasing stresses.

Loading Conditions

In the first loading condition, the distribution of 500 N load was extended over a large area inside the framework arch determining an overall greater stress on both the connection types (MUA or OT-Bridge). Passing from the first to the second loading condition (400 N applied on a 7-mm distal cantilever), tension and deformation decreased for all the tested models. However, the deformation was much more concentrated in the region where the load is applied near the distal cantilever. This is in relation to loading application, involving a bending moment of the prosthetic framework with related tension in all the prosthetic components, especially in the bar region between the anterior and the distal implant after the first implant prosthetic connection.

Other FEM analysis in literature evaluating framework materials, abutment systems, and loading conditions can be found. Rubo et al[30] found that stress increase proportionally to the increase in cantilever length and inversely to the increase in the elastic modulus of cancellous bone. Moreover, they concluded that a stiffer framework may allow better stress distribution, which is in accordance with our study results. This relation about rigidity and stress distribution was also highlighted by other studies testing polymeric materials (polyether ether ketone and polyetherketoneketone) at FEM.[32]

Regarding abutment type, rigid abutment design showed to decrease the peak stresses in the screw and the deflection of the superstructure.[33,34] In addition, in another study, 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 compared to a stepped cylinder implant connected to a screw-retained, internal hexagonal abutment.[35] In our study, we focused only on the prosthetic components, but it is important to underline that the design of implant-abutment interface could affect the surrounding bone tissue. Conical implant-abutment interface decreased the stress at bone-implant interface, resulting also in a more apical shear stress transmission compared to the flat top interface.[36]

About the OT-Bridge system, only one FEM was published by Cervino et al[17]; however, they focused on the stability of OT Bridge prosthesis in an All-On-Four mandibular model, concluding that at maximum one abutment can be unscrewed to ensure an adequate stability of the system. In another FEM evaluating different overdenture attachments,[31] the locator and OT-Equator system was found to offer better stress distribution compared to the traditional universal abutment. Furthermore, OT-Equator favored a higher stress on the retainer gum with minor stress located around the peri-implant bone tissue and fixture. This favorable stress distribution of OT-Equator attachment was also recognized in our study, where it was able to dissipate stress tensions over an extended area, differently from MUA.

Concerning forces application, the literature demonstrated that cantilever loading increased stress proportionally to its length.[30] In addition, stresses clustered at the elements closest to the loading point distribution. This is in accordance with our study where tension stresses in the cantilever loading condition was spread especially in the portion of the framework near the closest abutment. Literature

provided also evidence that axial and nonaxial occlusal loads influence both stress distribution on prosthetic components and on the bone remodeling phenomena.[37,38]

Despite the advantages of finite element analysis in the biomedical area,[29] a virtual simulation of a clinical condition using a computer software is limited.[39] In addition, in this study, only two loading conditions in two different moments were tested with a unidirectional loading while the occlusion normally produces multidirectional forces also in simultaneous moments. The framework design and the section of the bar are also related to the clinical case, and this could affect the mechanical properties and the distribution of the loading forces. Furthermore, ceramization of the prosthetic framework may change the pattern and the magnitude of occlusion forces distribution on framework bar, screws, and abutment. Then, further investigation and studies with more samples, and possibly *in vivo* conditions are required to evaluate the effectiveness of the All-On-Three technique and of the OT-Bridge system.

Conclusion

Metal alloy materials reduce the framework deformation during loadings because of the high mechanical properties. The OT-Bridge system raised the mechanical properties of the framework because of its smaller size and spread tension stresses more uniformly than MUA. Cantilever loading concentrated stress tensions and deformation in smaller areas for all the connection systems.

Authors' Contributions

S.C. and F.G.: Concept/design and data analysis interpretation.
E.M.Z. and F.G.: Drafting article.
S.C.: Critical revision of article and approval of article.
F.M., M.C.P., and C.M.G.: Data collection.

Conflict of Interest

The authors declare no conflict of interest.

Acknowledgment

The authors would thank the Department of Engineering of the University of Ferrara for their support in the study.

References

1 Mobilio N, Catapano S. The use of monolithic lithium disilicate for posterior screw-retained implant crowns. J Prosthet Dent 2017; 118(06):703–705
2 Mobilio N, Fasiol A, Catapano S. Survival rates of lithium disilicate single restorations: a retrospective study. Int J Prosthodont 2018; 31(03):283–286
3 Ciabattoni G, Acocella A, Sacco R. Immediately restored full arch-fixed prosthesis on implants placed in both healed and fresh extraction sockets after computer-planned flapless guided surgery. A 3-year follow-up study. Clin Implant Dent Relat Res 2017; 19(06):997–1008
4 Taylor TD. Fixed implant rehabilitation for the edentulous maxilla. Int J Oral Maxillofac Implants 1991;6(03):329–337
5 Cawood JI, Howell RA. A classification of the edentulous jaws. Int J Oral Maxillofac Surg 1988;17(04):232–236
6 Pozzi A, Holst S, Fabbri G, Tallarico M. Clinical reliability of CAD/CAM cross-arch zirconia bridges on immediately loaded implants placed with computer-assisted/template-guided surgery: a retrospective study with a follow-up between 3 and 5 years. Clin Implant Dent Relat Res 2015;17(Suppl 1):e86–e96
7 Pellegrino G, Grande F, Ferri A, Pisi P, Gandolfi MG, Marchetti C. Three-dimensional radiographic evaluation of the malar bone engagement available for ideal zygomatic implant placement. Methods Protoc 2020;3(03):E52
8 Maló P, de Araújo Nobre M, Lopes A, Francischone C, Rigolizzo M. "All-on-4" immediate-function concept for completely edentulous maxillae: a clinical report on the medium (3 years) and long-term (5 years) outcomes. Clin Implant Dent Relat Res 2012;14 (Suppl 1):e139–e150
9 Balshi TJ, Wolfinger GJ, Slauch RW, Balshi SF. A retrospective analysis of 800 Brånemark System implants following the All-on-Four™ protocol. J Prosthodont 2014;23(02):83–88
10 Tallarico M, Meloni SM, Canullo L, Caneva M, Polizzi G. Five-year results of a randomized controlled trial comparing patients rehabilitated with immediately loaded maxillary cross-arch fixed dental prosthesis supported by four or six implants placed using guided surgery. Clin Implant Dent Relat Res 2016;18(05):965–972
11 Landázuri-Del Barrio RA, Cosyn J, De Paula WN, De Bruyn H, Marcantonio E Jr. A prospective study on implants installed with flapless-guided surgery using the all-on-four concept in the mandible. Clin Oral Implants Res 2013;24(04):428–433
12 Pjetursson BE, Brägger U, Lang NP, Zwahlen M. Comparison of survival and complication rates of tooth-supported fixed dental prostheses (FDPs) and implant-supported FDPs and single crowns (SCs). Clin Oral Implants Res 2007;18(Suppl 3):97–113
13 Goodacre CJ, Bernal G, Rungcharassaeng K, Kan JYK. Clinical complications with implants and implant prostheses. J Prosthet Dent 2003;90(02):121–132
14 Sailer I, Mühlemann S, Zwahlen M, Hämmerle CHF, Schneider D. Cemented and screw-retained implant reconstructions: a systematic review of the survival and complication rates. Clin Oral Implants Res 2012;23(Suppl 6):163–201
15 Catapano S, Ferrari M, Mobilio N, Montanari M, Corsalini M, Grande F. Comparative analysis of the stability of prosthetic screws under cyclic loading in implant prosthodontics: an in vitro study. Appl Sci (Basel) 2021;11(02):622
16 Pozzan MC, Grande F, Mochi Zamperoli E, Tesini F, Carossa M, Catapano S. Assessment of preload loss after cyclic loading in the OT Bridge system in an "All-on-Four" rehabilitation model in the absence of one and two prosthesis screws. Materials (Basel) 2022; 15(04):1582
17 Cervino G, Cicciù M, Fedi S, Milone D, Fiorillo L. FEM analysis applied to OT Bridge abutment with Seeger retention system. Eur J Dent 2021;15(01):47–53
18 Corsalini M, Barile G, Catapano S, et al. Obturator prosthesis rehabilitation after maxillectomy: functional and aesthetical analysis in 25 patients. Int J Environ Res Public Health 2021;18 (23):12524
19 Ortensi L, Ortensi M, Minghelli A, Grande F. Implant-supported prosthetic therapy of an edentulous patient: clinical and technical aspects. Prosthesis 2020;2(03):140–152
20 Ortensi L, Martinolli M, Borromeo C, et al. Effectiveness of ball attachment systems in implant retained- and supported-overdentures: a three- to five-year retrospective examination. Dent J 2019;7(03):E84
21 Acampora R, Montanari M, Scrascia R, et al. 1-year evaluation of OT Bridge abutments for immediately loaded maxillary fixed restorations: a multicenter study. Eur J Dent 2021;15(02): 290–294
22 Ayna M, Sagheb K, Gutwald R, et al. A clinical study on the 6-year outcomes of immediately loaded three implants for completely edentulous mandibles: "the all-on-3 concept". Odontology 2020; 108(01):133–142

 © 2023. The Author(s).

23 Beresford D, Klineberg I. A within-subject comparison of patient satisfaction and quality of life between a two-implant overdenture and a three-implant-supported fixed dental prosthesis in the mandible. Int J Oral Maxillofac Implants 2018;33(06):1374–1382
24 Cannizzaro G, Cavallari M, Lazzarini M, et al. Immediate loading of three (fixed-on-3) vs four (fixed-on-4) implants supporting cross-arch fixed prostheses: 1-year results from a multicentre randomised controlled trial. Eur J Oral Implantology 2018;11(03):323–333
25 Oliva J, Oliva X, Oliva JD. All-on-three delayed implant loading concept for the completely edentulous maxilla and mandible: a retrospective 5-year follow-up study. Int J Oral Maxillofac Implants 2012;27(06):1584–1592
26 Bhering CLB, Mesquita MF, Kemmoku DT, Noritomi PY, Consani RLX, Barão VAR. Comparison between all-on-four and all-on-six treatment concepts and framework material on stress distribution in atrophic maxilla: a prototyping guided 3D-FEA study. Mater Sci Eng C 2016;69:715–725
27 Papaspyridakos P, Bordin TB, Kim YJ, et al. Technical complications and prosthesis survival rates with implant-supported fixed complete dental prostheses: a retrospective study with 1- to 12-year follow-up. J Prosthodont 2020;29(01):3–11
28 Cook SD, Klawitter JJ, Weinstein AM. The influence of implant geometry on the stress distribution around dental implants. J Biomed Mater Res 1982;16(04):369–379
29 Brown CU, Norman TL, Kish VL III, Gruen TA, Blaha JD. Time-dependent circumferential deformation of cortical bone upon internal radial loading. J Biomech Eng 2002;124(04):456–461
30 Rubo JH, Capello Souza EA. Finite-element analysis of stress on dental implant prosthesis. Clin Implant Dent Relat Res 2010;12 (02):105–113
31 Cicciù M, Cervino G, Milone D, Risitano G. FEM analysis of dental implant-abutment interface overdenture components and parametric evaluation of Equator® and Locator® prosthodontics attachments. Materials (Basel) 2019;12(04):E592
32 Villefort RF, Diamantino PJS, Zeidler SLVV, et al. Mechanical response of PEKK and PEEK as frameworks for implant-supported full-arch fixed dental prosthesis: 3D finite element analysis. Eur J Dent 2022;16(01):115–121
33 Holmes DC, Haganman CR, Aquilino SA. Deflection of superstructure and stress concentrations in the IMZ implant system. Int J Prosthodont 1994;7(03):239–246
34 Papavasiliou G, Tripodakis AP, Kamposiora P, Strub JR, Bayne SC. Finite element analysis of ceramic abutment-restoration combinations for osseointegrated implants. Int J Prosthodont 1996;9 (03):254–260
35 Quaresma SET, Cury PR, Sendyk WR, Sendyk C. A finite element analysis of two different dental implants: stress distribution in the prosthesis, abutment, implant, and supporting bone. J Oral Implantol 2008;34(01):1–6
36 Hansson S. Implant-abutment interface: biomechanical study of flat top versus conical. Clin Implant Dent Relat Res 2000;2(01): 33–41
37 Holmgren K, Sheikholeslam A, Riise C. Effect of a full-arch maxillary occlusal splint on parafunctional activity during sleep in patients with nocturnal bruxism and signs and symptoms of craniomandibular disorders. J Prosthet Dent 1993;69(03): 293–297
38 Barbier L, Vander Sloten J, Krzesinski G, Schepers E, Van der Perre G. Finite element analysis of non-axial versus axial loading of oral implants in the mandible of the dog. J Oral Rehabil 1998;25(11): 847–858
39 Geng JP, Tan KBC, Liu GR. Application of finite element analysis in implant dentistry: a review of the literature. J Prosthet Dent 2001; 85(06):585–598

 © 2023. The Author(s).