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RESEARCH AND EDUCATION

Implant-supported overdentures with different clinical configurations: Mechanical resistance using a numerical approach

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ABSTRACT

Statement of problem. Implant-supported overdentures (IODs) are a treatment option for patients with complete edentulism. However, this treatment increases the possibilities of peri-implant complications, characterized by inflammation or partial loss of surrounding hard and soft tissues.

Purpose. The purpose of this finite element analysis study was to evaluate the mechanical performance of different bar-IOD designs under different clinical configurations by comparing the stress and strain distribution on the bone during secondary stabilization.

Material and methods. A finite element model of the mandible representing a patient with complete edentulism was developed. Different designs of bar-IODs were modeled and compared. The parameters studied were the material properties (cobalt-chromium, zirconium dioxide, titanium grade 5, and titanium grade 4), diameter and bar-IOD cross-sectional shape, tilt of the posterior implants (30 degrees), presence of a distal extension cantilever in the bar-IODs (12 mm), and number of implants (4 or 6). Two different mastication loading conditions were analyzed. One- and 2-way ANOVAs and the Tukey honestly significant differences post hoc test (α=.05) were used to determine the significant von Mises stress and strain values in the bone.

Results. The 4 materials tested in the bar-IOD did not have a significant mechanical effect on the bone (*P*<.05). A smaller diameter and structure of the bar-IOD led to significantly higher bone stress (*P*<.001). A distal extension cantilever led to an increased stress concentration (model M1 versus model M3: *P*<.001), which reached 50% in the event of tilting of the posterior implants (model M2 versus model M4: *P*<.001). Tilting of the posterior implants alone, without extension, had a nonsignificant effect (model M3 versus model M4: *P*=.999). Model M5 supported with 6 implants reduces the stress transferred to the bone compared with model M3 supported with 4 implants (*P*<.05).

Conclusions. Distal extensions in bar-IODs, the tilt of the posterior implants, and the low amount of material in the cross-sectional area in the bar-IOD were the most influential parameters on the mechanical resistance of dental implants in the mandibular bone. (J Prosthet Dent 2019;121:546.e1-e10)

Dental implants are used in the treatment of partial or total tooth loss, with a success rate of over 90%.[1,2] For patients with complete edentulism, conventional dentures, implant-supported fixed complete dentures, and implant-supported/retained overdentures (IODs) are alternatives for restoring the function and esthetics.[3] A higher level of comfort has been reported by patients with IOD and fixed complete denture systems,[4-6] with similar clinical success rates.[7-9]

IOD systems include ball, bar, or magnetic attachments with different materials.[10-14] Sometimes, with tilted implants[7] of different sizes,[10,15,16] implants and/or prosthetic elements of different designs are combined.[17-19] Different solutions are available for dental

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Clinical Implications

Implant-supported overdenture designs make a significant difference in the mechanical stability of dental implants. The bar–implant-supported overdenture design can be used to decrease the risk of damage to the bone.

implant treatments, but the choice for each patient is complex and the decision-making process is based on the dentists' experience and clinical evidence.[20,21]

When compared with conventional complete dentures, implant-supported restorations may lead to clinical complications characterized by inflammation or partial loss of surrounding tissue. Also, peri-implant complications are most common in the second year after implant placement.[22] Stability problems are caused by bacterial infections and by mechanical factors mainly associated with parafunctional habits such as bruxism.[23-25] The design parameters known to influence the mechanical resistance of implant solutions and therefore minimize the risks of complications include the number of implants; treatments with a number of implants on IODs (1 to 6) in patients with complete edentulism have been reported.[4,8,26,27] Adequate retention in the mandible from 2 to 4 implant overdentures has been reported, with no significant difference in the clinical radiographic condition during a 10-year evaluation period.[27] In patients with an edentulous maxilla, the risk is higher when fewer than 4 implants are placed.[8]

Posterior implant tilting and a distal extension cantilever in bar-IOD have been used in some situations. A tilt angle between 25 and 45 degrees has been described according to the anatomic site.[7,22] A high risk of fracture has been observed with a distal extension cantilever in a bar-IOD.[11,28] These complications might be minimized by a different bar-IOD design.[29,30]

As the clinical situations are varied and sometimes complex, numerical simulation can help clinicians better evaluate and understand the consequences of the choice of treatment.[3,31,32] The purpose of this finite element analysis study was to compare various bar-IOD designs for completely edentulous patients, taking the mechanical resistance of the dental implants during secondary stabilization in the mandibular bone as the comparison criterion. The null hypothesis was that the material properties, diameter and bar-IOD cross-sectional shape, tilt of the posterior implants, presence of distal extension cantilever in bar-IODs, and number of implants (4 or 6) would not generate any significant differences on stress and strain distribution in bone.

MATERIAL AND METHODS

A finite element model of a mandible with complete edentulism fitted with an IOD with 4 parallel implants was defined as a reference configuration (Fig. 1). This reference model was subjected to a sensitivity analysis to quantify the influence of 3 parameters of the bar-IOD: material properties (cobalt-chromium, titanium grade 5, titanium grade 4, and zirconium dioxide), diameter (0.5 mm, 1 mm, 2 mm, 4 mm, and 6 mm), and cross-sectional shape (square, circular, L-shape, and rectangular) on mechanical resistance during secondary stability of the dental implants. The performance of the reference model was compared with 4 variants to estimate the influence of tilting the posterior implants, adding a posterior distal extension cantilever, and supporting the bar-IOD with 6 rather than 4 implants.

Computed tomography scan images (Sensation 64 CT; Siemens) of a human mandible dissected from a cadaver of the Thanatopraxy Department of the Faculty of Medicine, Aix-Marseille University, were imported into the Mimics software (Mimics v12.3; Materialise) for 3D segmentation and reconstruction. The protocol complied with the ethical standards of the institution.

Commercially available implants (IDP-IMP-M3.75-13; Saddle Implants) and prosthetic screws (IDP-VPMU; Saddle Implants) were selected for this reference model and were considered generic. The 3D geometry came from the computer-assisted design (CAD) provided by the manufacturer. The circular geometry of the bar-IOD with a 4-mm diameter was specifically designed for this study (Fig. 1). The fixation system between the dental implants and the bar-IOD was produced by adding a standard-size prosthetic screw as seen in Figure 1.

To simulate the osseointegration of the dental implants to secondary stabilization, 0.2-mm-thick lamellar bone[33,34] was modeled as a layer around each implant (Fig. 1). The thickness of the cortical bone was set at 2 mm to accommodate Type II mandibular bone according to the Lekholm and Zarb classification.[35] A mesh was produced from these geometries in the software (Hypermesh v.12; Altair) using triangular shell elements and tetrahedral elements for volume meshing to create the finite element models. Refinement of the meshing of dental implants was assumed with a minimum size of 60 μm, as in a previous study,[36] and was adapted in the contact zones with bone and prosthetic components (Fig. 1). The resulting mesh characteristics are summarized in Table 1.

The dental implants were considered to be fully integrated (Fig. 1). The interfaces between the meshing of the cortical bone, cancellous bone, lamellar bone, and dental implants were modeled using a continuous mesh. Kinematic conditions were added to describe the rigid interactions between the dental implants, screws,

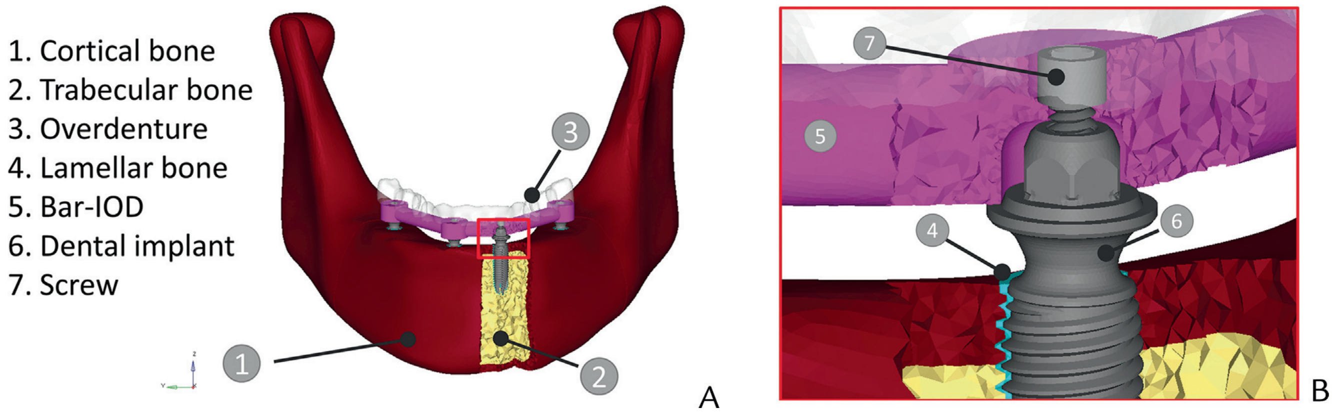

Figure 1. A, Reference numerical model, configuration with 4 dental implants in secondary stability conditions. B, Close up of area of interest. IOD, implant-supported overdenture.

Table 1. Meshing characteristic

System Components	Surface Meshing		Volume Meshing	
	Number of Elements	Minimum Size	Number of Elements	Minimum Size
4 Dental implants	120 838	0.060 mm	514 254	0.023 mm
4 Connecting screws	12 980	0.032 mm	542 222	0.022 mm
1 Bar-IOD	89 840	0.059 mm	960 919	0.032 mm
Bone	232 188	0.060 mm	1 830 148	0.012 mm

IOD, implant-supported overdenture.

Table 2. Mechanical properties

Materials	ρ (Density G/mm^3)	E (Young Modulus MPa)	ν (Poisson Ratio)	Reference
Lamellar bone	0.0015	13 700	0.33	33
Cortical bone	0.0015	13 700	0.33	37
Trabecular bone	0.001015	1370	0.3	37
Grade 5 titanium	0.0045	114 000	0.33	36
Grade 4 titanium	0.0084	104 500	0.37	36

overdenture, and bar-IOD. The overdenture was modeled as a rigid body, and the influence of overdenture materials and attachment systems was not considered. Embedding conditions for the condyles were modeled as fixed.

The bone was assumed to follow a linear elastic behavior. Young modulus, density, and Poisson ratio for the bone were obtained from data in the literature and are summarized in Table 2. The mechanical properties of the dental implants (grade 4 titanium), bar-IOD, and prosthetic screws (grade 5 titanium) are also summarized in Table 2.

Two bone damage criteria were used: by strain, based on Mechanostat,[38,39] which takes into account the physiological strain (appropriate conditions for good dental implant resistance in secondary stabilization conditions: 200 με-3000 με), overload strain (bone suffering minor damage: 3000 με-4000 με), pathological strain (highly probable rupture: 4000 με-8000 με), and maximum strain before rupture defined in this study [8000 με]; and by stress, the elastic limit of the bone (cortical bone and lamellar bone) was used as a pathological damage threshold. The value defined in this study was 110 MPa.[40,41]

The relevant quantitative data of the stress and strain in the bone were analyzed by a 1-way ANOVA for the sensitivity analysis and by a 2-way ANOVA for the evaluation of clinical configurations, followed by the Tukey honestly significant differences post hoc test (α=.05 for all tests). Analyses were performed using a statistical software program (RStudio Desktop; RStudio).

A sensitivity analysis was performed to quantify the influence of the characteristics of the dental implants on mechanical resistance under secondary stabilization conditions. Three sets of parameters of the bar-IOD were tested: material properties, diameter, and cross-sectional shape.

The bar-IOD was tested with 4 different materials: titanium grade 4, titanium grade 5 (reference model), cobalt-chromium, and zirconium dioxide; the mechanical properties of these materials are summarized in Table 3. Five bar diameters were tested to determine the influential geometric factors of the bar-IOD: 0.5 mm, 1 mm, 2 mm, 4 mm (reference model), and 6 mm. Four cross-sectional shapes were tested: circular profile (reference model), square profile, L-shaped profile, and rectangular profile (Fig. 2).

The loading condition was assumed as a normal mastication condition. The load was applied to the left half of the mandible (Fig. 3A) bearing 2 incisors, 1 canine, 2 premolars, and the first molar. A 235-N oblique load was applied with a 30-degree inclination in the linguo-buccal direction,[42] which was the expected load for an edentulous person.[16] Load was distributed differently on each tooth as suggested by Blamphin et al.[43] The loads were 24 N for each incisor and the canine, 50 N for each premolar, and 63 N for the first molar.

Table 3. Mechanical properties of bar-IODs

Materials	ρ (Density G/mm3)	E (Young Modulus MPa)	ν (Poisson Ratio)	Yield Stress (σy MPa)	Ultimate Tensile Strength (σ_{max} MPa)	Stiffness
Cobalt-chromium	0.0084	220 000	0.3	980	1300	+
Zirconium dioxide	0.0061	205 000	0.3	–	1000*	
Grade 5 titanium	0.0045	114 000	0.33	940	1054	
Grade 4 titanium	0.0043	104 500	0.37	650	798	-

IOD, implant-supported overdenture. *Flexural strength.

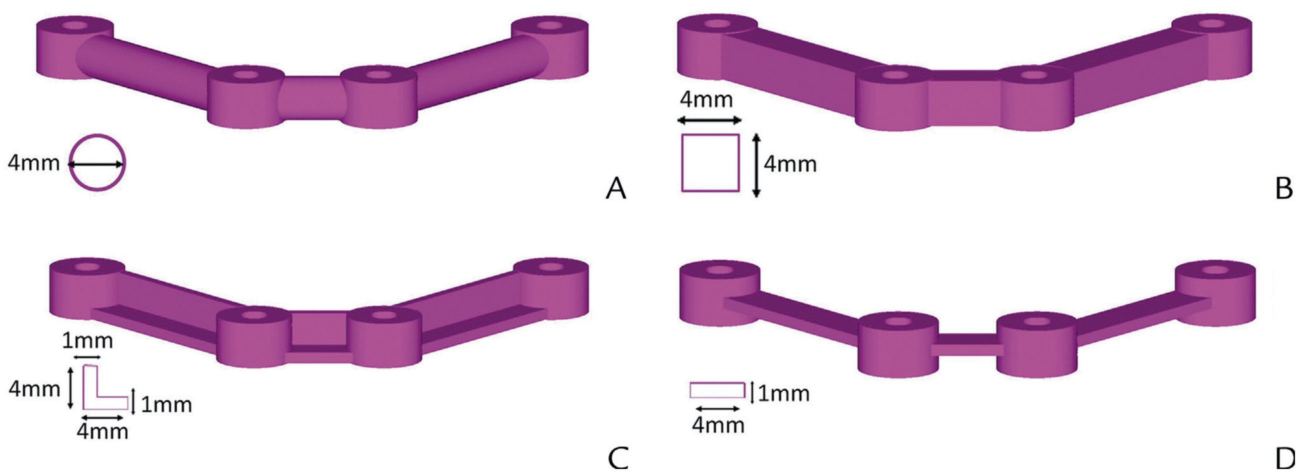

Figure 2. Bar-IOD cross-sectional profiles. A, Circular profile. B, Square profile. C, L-shaped profile. D, Rectangular profile. IOD, implant-supported overdenture.

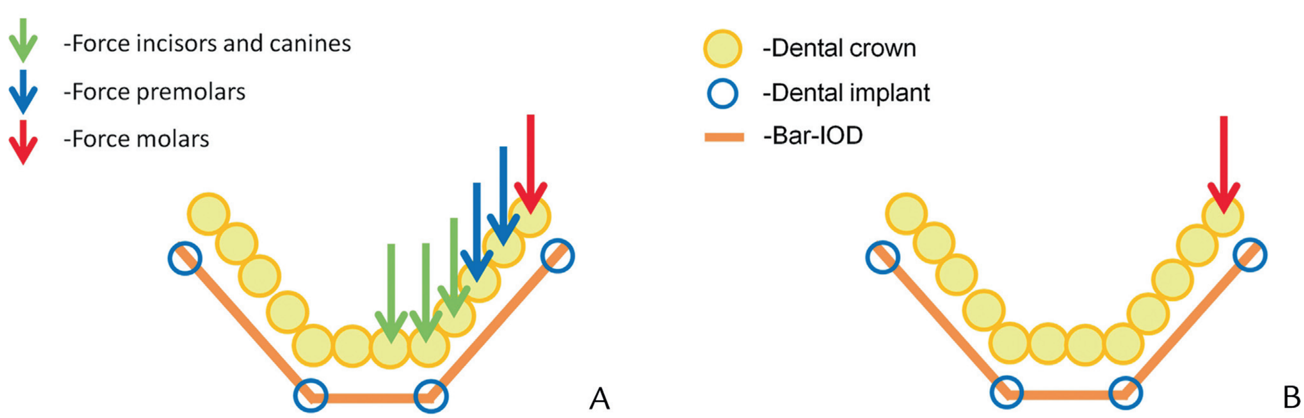

Figure 3. Loading condition. A, Half mandible (normal load). B, Left first molar (critical load). IOD, implant-supported overdenture.

Evaluation of the mechanical performances of the various configurations was performed considering von Mises stress for ductile materials and principal stress for nonductile materials (zirconium dioxide),[44] whereas strain was recorded for the bone only. The 100 values of stress and strain around the maximum peak were recorded for each component.

The clinical conditions tested are described in Table 4 and are seen in Figure 4. The parameters studied were the tilt of the posterior implants (30 degrees),[22,45] investigated by comparing model M3 (reference) and model M1 with models M4 and M2, respectively; the presence of a distal extension cantilever in the bar-IOD (12 mm),[46] investigated by comparing model M3 (reference) and model M4 with models M1 and M2, respectively; and the total number of implants (4 or 6) supporting the bar-IOD,[8] investigated by comparing models M3 (reference) and M5.

For this study, 2 mastication loading conditions were applied. The first was considered to be a normal situation, in which 235 N was applied to the left half of the mandible (Fig. 3A). The second condition was defined as

Table 4. Clinical configurations

Clinical Configurations	Number of Implants	Anatomic Location	Inclination of Posterior Implants	Dimensions of Extensions
Model M1	4	LFPM-LSI-RSI-RFPM	0 degrees	12 mm
Model M2	4	LFPM-LSI-RSI-RFPM	30 degrees	12 mm
Reference model M3	4	LFM-LSI-RSI-RFM	0 degrees	0 mm
Model M4	4	LFM-LSI-RSI-RFM	30 degrees	0 mm
Model M5	6	LFM- LFPM -LSI-RSI-RFPM-RFM	0 degrees	0 mm

LFM, left first molar; LFPM, left first premolar; LSI, left second incisor; RFM, right first molar; RFPM, right first premolar; RSI, right second incisor.

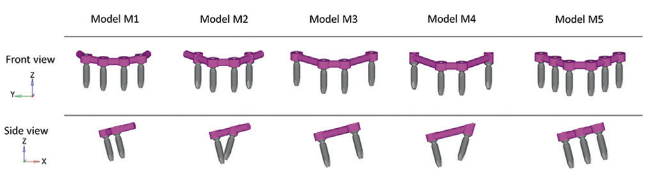

Figure 4. Clinical configurations tested.

critical. In this second situation, the load was applied to the first molar only with a value of 235 N (Fig. 3B). The outcome measures were the same.

RESULTS

The von Mises stress and strain transmitted to the bone from the cobalt-chromium bar-IOD and zirconium dioxide bar-IOD (P=.998) and between titanium grade 5 bar-IOD and titanium grade 4 bar-IOD (P=.732) were statistically similar. The difference was significantly different (P<.05) for all the other comparisons of evaluated materials in the bar-IOD. The von Mises stress distribution in bone is seen in Figure 5. Table 5 provides the details for the stress and strain values.

The von Mises stress and strain transferred to the bone were computed for 5 different bar-IOD diameters. The difference between the bar-IOD ∅6 mm versus bar-IOD ∅4 mm was not significantly different (P=.664). The differences for the other diameters were significantly different: bar-IOD ∅4 mm versus bar-IOD ∅2 mm (P<.001); bar-IOD ∅2 mm versus bar-IOD ∅1 mm (P<.001); bar-IOD ∅1 mm versus bar-IOD ∅0.5 mm (P<.001). The von Mises stress transferred to the bone is shown in Figure 6, and mean ±standard deviation (SD) levels are described in Table 6.

When the von Mises stress and strain in the bone for the 4 cross-sectional shape were compared, the circular profile versus the L-shaped profile were not statistically different (P=.999). The differences between the other profiles were significant: circular profile versus square profile (P=.034); square profile versus L-shaped profile (P=.025); and all the other profiles versus rectangular profile (P<.001). The von Mises stress in the 4 models is shown in Figure 7. Table 7 provides the details of mean ±SD levels.

A statistical analysis of clinical configurations showed a significant difference between the 2 loading conditions (P<.001) for the stress and strain values transmitted to the bone. Under the first loading condition, considered to be normal mastication, the tilting of the posterior implants in model M1 versus model M2 was significantly different (P<.001), but not for model M3 versus model M4 (P=.810). The difference with or without a distal extension cantilever in model M1 versus model M3 was not significantly different (P=.231) but was significantly different for model M2 versus model M4 (P<.001). For the total number of implants, the difference between model M3 versus model M5 was significantly different (P<.001).

Under the second loading condition, defined as critical, the only difference that was not statistically significant was the tilting of the posterior implants in model M3 versus model M4 (P=.999). The difference between the total number of implants in the model M3 versus model M5 was significantly different (P=.039), and all the other comparisons were also found to be statistically significant (P<.001). In both the loading conditions, the location of the maximum von Mises stress levels and strains in the bone was observed in the crestal area around the left posterior implant (Fig. 8). Table 8 shows the detailed results for mean ±SD levels.

DISCUSSION

Numerical simulation by finite element analysis was used to evaluate the mechanical resistance of endosseous dental implants in conditions of secondary stabilization in the mandible. The null hypothesis was rejected because, to varying degrees, the material properties, the diameter, and cross-sectional shape of the bar-IOD; the tilt of the posterior implants; the presence of distal extension cantilever in the bar-IOD; and the number of implants had a mechanical effect on the bone.

Among the 4 materials tested in this study for the bar, the hardness of the material had little effect on the mechanical resistance of the dental implants in the mandibular bone. The risk of fracture in the system components is considered low. The strains recorded in the bone for the 4 tested materials were identified in a physiological zone. According to Mechanostat,[38,39] this strain level keeps bone growth and resorption in a stable state. Biocompatibility, fatigue, and material risk of degradation were not modeled in this study.

The diameter of the bar had a significant influence on the stabilization of dental implants. With a diameter of less than 1 mm, the strain would exceed the pathological zone, leading to damage in the bone with a high risk of rupture. Also, with a diameter of less than 2 mm, the maximal stress value increases to

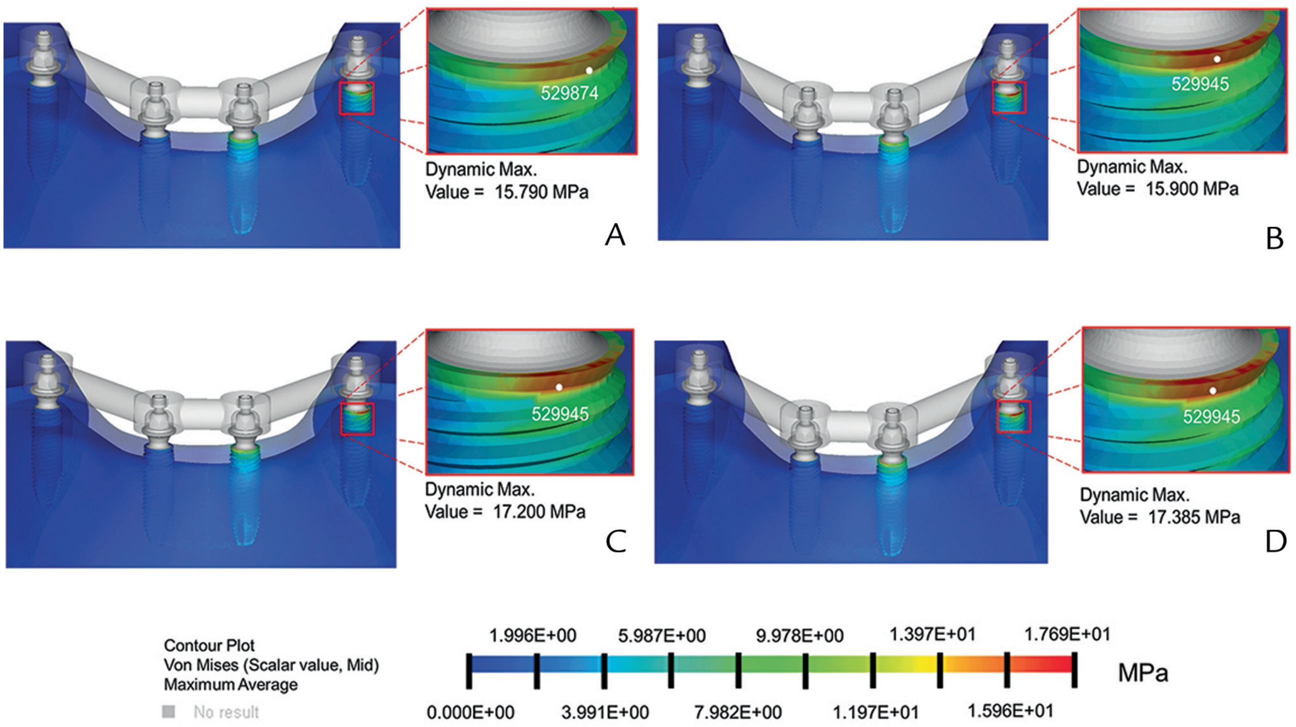

Figure 5. von Mises stress transferred to bone in normal mastication conditions, influence of materials. A, Cobalt-chromium bar-IOD. B, Zirconium dioxide bar-IOD. C, Titanium grade 5 bar-IOD. D, Titanium grade 4 bar-IOD. IOD, implant-supported overdenture.

Table 5. Bar-IOD material, mean ±SD levels of stress and strain in normal mastication conditions

Half-Mandibular Loading	Cobalt Chromium	Zirconium Dioxide	Titanium Grade 5	Titanium Grade 4
Bone stress	9.9 ±4.1 MPa	10.0 ±4.1 MPa	12.1 ±3.5 MPa	11.5 ±4.0 MPa
Bone strain	726.0 ±298.6 με	803.0 ±320.9 με	884.0 ±256.9 με	733.0 ±300.3 με
Dental implant stress	71.0 ±17.9 MPa	76.1 ±14.3 MPa	94.3 ±14.6 MPa	90.3 ±19.5 MPa
Screws stress	29.0 ±8.3 MPa	28.3 ±10.6 MPa	34.3 ±9.5 MPa	36.4 ±8.7 MPa
Bar-IOD stress	47.3 ±25.6 MPa	32.1 ±22.1 MPa	68.9 ±29.1 MPa	60.5 ±30.9 MPa

IOD, implant-supported overdenture; SD, standard deviation.

more than 50% and exceeds the yield stress of the bar, raising the risk of fracture of the system components. Based on these results, a diameter of more than 2 mm should be considered in designing a bar for an IOD.

Except for the rectangular shape that had less material and cross-sectional area, modifying the shape of the bar had little influence on the levels of stress and strain transferred to the bone. These results were expected as increasing the cross-section of the bar and adding an abutment had a positive effect on the mechanical resistance during fatigue testing.[30] These results suggest that the choice of the cross-sectional shape of the bar is not critical.

A significant difference was observed between both the loading conditions. The loading condition defined as critical generated a higher stress and strain level in all the components and can be associated with an overload condition.

Concerning the tilt of the posterior implants, a significant difference was observed between model M1 and model M2, where tilted posterior implants were found to increase the risk of bone damage considerably. No significant difference was found when comparing bone damage risks in models M3 and M4. According to these results, tilting posterior implants is not a relevant clinical option in all situations. Despite similar observations reported by Almeida et al,[45] tilting of implants is still considered a treatment option by dentists because of its supposedly better mechanical performance.[7,22] Note that in the present study, only a 30-degree tilt angle was tested; however, angles ranging from 20 to 45 degrees have been proposed.[22] Also note that only 1 bone quality was assesed (Type II). Therefore, situations do exist for which the conclusions in this study may not be valid and for which a posterior tilt might be justified, such as a different angle of tilt or a different bone quality (Type I, III, or IV).

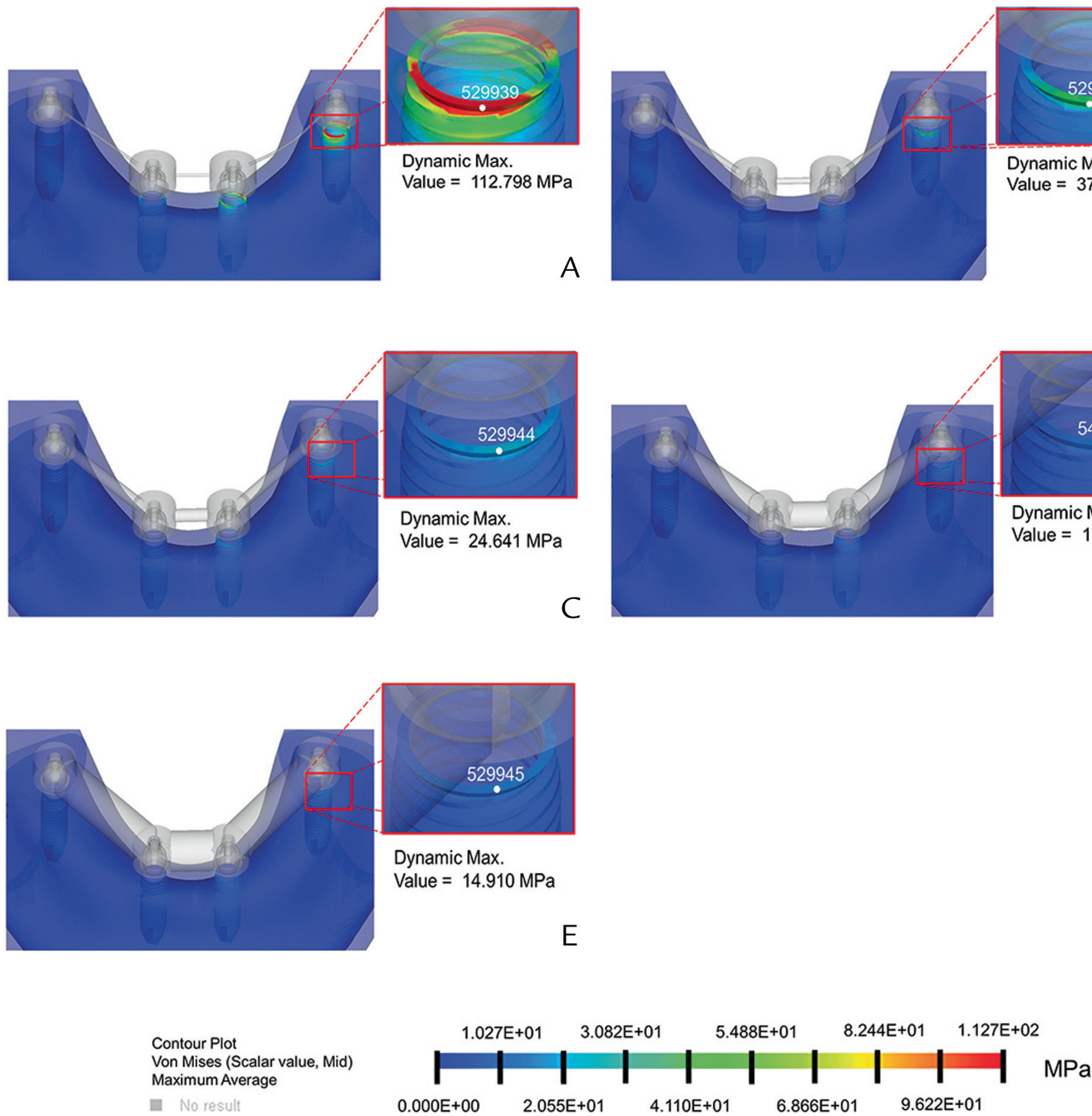

Figure 6. von Mises stress transferred to bone in normal mastication conditions, influence of bar-IOD diameters. A, 0.5 mm. B, 1.0 mm. C, 2.0 mm. D, 4.0 mm. E, 6.0 mm.

Table 6. Bar-IOD diameters, mean ±SD levels of stress and strain in normal mastication conditions

Half-Mandibular Loading	Diameter 0.5 mm	Diameter 1 mm	Diameter 2 mm	Diameter 4 mm	Diameter 6 mm
Bone stress	79.5 ±21.9 MPa	26.4 ±5.9 MPa	19.0 ±3.1 MPa	12.1 ±3.5 MPa	10.1 ±3.5 MPa
Bone strain	5810.0 ±1598.3 με	1930.0 ±431.1 με	1390.0 ±222.7 με	884.0 ±256.9 με	739.0 ±253.8 με
Dental implant stress	533.0 ±94.1 MPa	225.0 ±58.7 MPa	169.0 ±26.3 MPa	94.3 ±14.6 MPa	60.7 ±11.2 MPa
Screw stress	112.0 ±49.5 MPa	63.9 ±23.0 MPa	47.9 ±13.7 MPa	34.3 ±9.5 MPa	30.1 ±8.1 MPa
Bar-IOD stress	1054.0 ±0 MPa	878.0 ±251.3 MPa	184 ±42.1 MPa	68.9 ±29.1 MPa	20.8 ±10.2 MPa

IOD, implant-supported overdenture; SD, standard deviation.

The presence of the distal extension cantilever of the bar increased the levels of stress and strain in the bone by up to 50%, representing a significant risk for the bone. These findings are consistent with previous studies.[11,28] However, Quirynen et al[30] reported that the addition of an abutment in the extension of the bar-IOD improved the mechanical resistance of the structure and that possible geometric variations in the extension of the bar, such as length and the abutment, could reduce the mechanical load on the bone, reducing the risks observed in the present study.

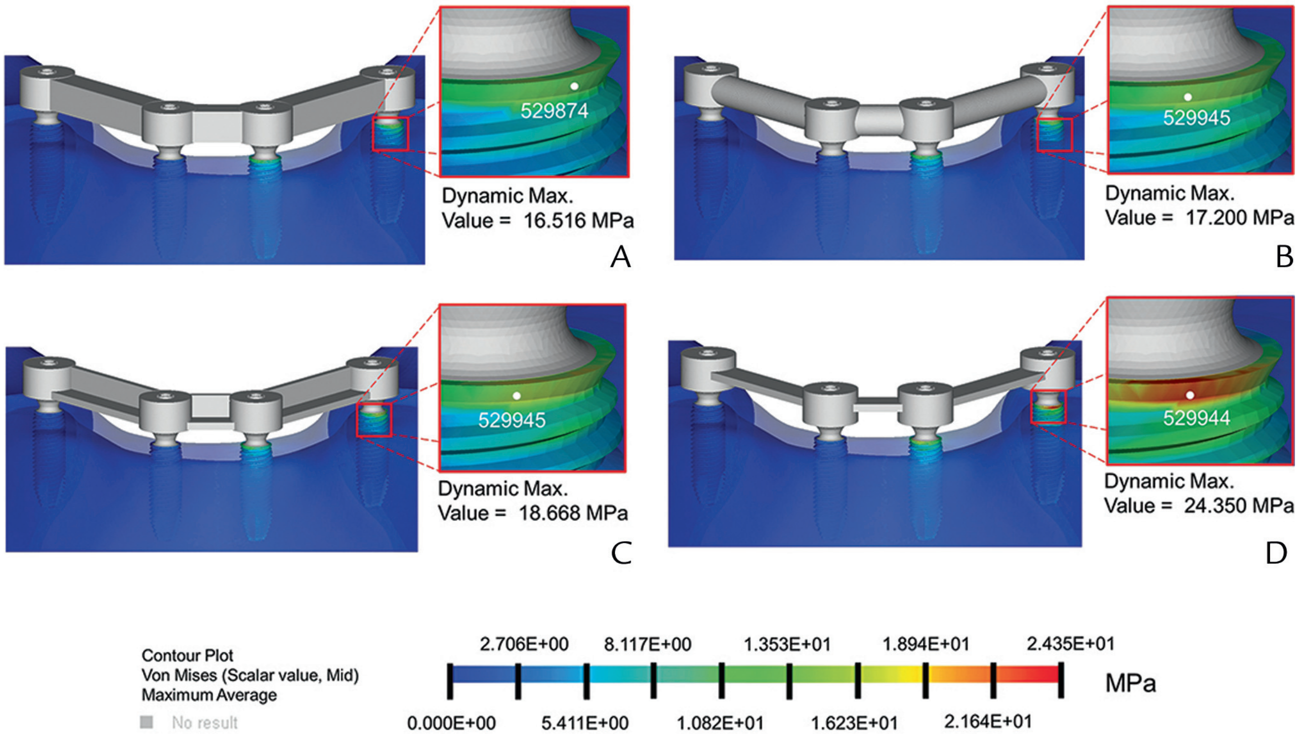

Figure 7. von Mises stress transferred to bone in normal mastication conditions, influence of bar-IOD cross-sectional shape. A, Square profile. B, Circular profile. C, L-shaped profile. D, Rectangular profile. IOD, implant-supported overdenture.

Table 7. Bar-IOD cross-sectional profiles, mean ±SD levels of stress and strain in normal mastication conditions

Half-Mandibular Loading	Square Profile	Circular Profile	L-Shaped Profile	Rectangular Profile
Bone stress	10.4 ±4.3 MPa	12.1 ±3.5 MPa	12.2 ±4.3 MPa	16.0 ±5.3 MPa
Bone strain	760.0 ±311.2 μɛ	884.0 ±256.9 μɛ	888.0 ±315.0 μɛ	1170.0 ±389.2 μɛ
Dental implant stress	73.7 ±20.1 MPa	94.3 ±14.6 MPa	95.7 ±19.0 MPa	160.0 ±31.7 MPa
Screw stress	35.2 ±8.1 MPa	34.3 ±9.5 MPa	36.3 ±9.6 MPa	44.4 ±13.2 MPa
Bar-IOD stress	37.7 ±17.3 MPa	68.9 ±29.1 MPa	95.4 ±24.7 MPa	117.0 ±51.9 MPa

IOD, implant-supported overdenture; SD, standard deviation.

Stress and strain levels in bone decreased for the model with 6 implants. However, the difference was small, and both the models had stress and strain levels well below the ultimate strength of bone. Therefore, the risk of damage is low with either 4 or 6 implants. This same behavior was reported in a previous study.[44] Under the conditions of this study, these results indicate that the benefits of the 6-implant configuration are not clearly justified. This is also confirmed by previous studies where long-term success rates with 4 or 6 implants were similar.[3,8]

Physiological conditions are different for each patient. Therefore, the results of this study should be interpreted cautiously, considering the geometry of the mandible, the selection of bone quality, the prosthetic elements, and the finite element models. The influence of the attachment systems and overdenture materials were not considered in this study. The 2 outcome measures considered in this study, von Mises stress and strain, were able to predict critical areas in the bone during mastication. These observations may be correlated with peri-implant issues, and further clinical validations are required. A bony Mechanostat damage model was used as injury strain-based criteria.[38] However, the pathological bony behavior, such as bone loss or peri-implant infections, was not addressed in this study.

CONCLUSIONS

Within the limitations of this finite element study, the following conclusion was drawn:

1. A distal extension cantilever in the bar-IOD, the tilt of the posterior implants, and the low amount of material in the cross-sectional area in the bar-IOD were the most influential parameters for the mechanical resistance of dental implants in the mandibular bone.

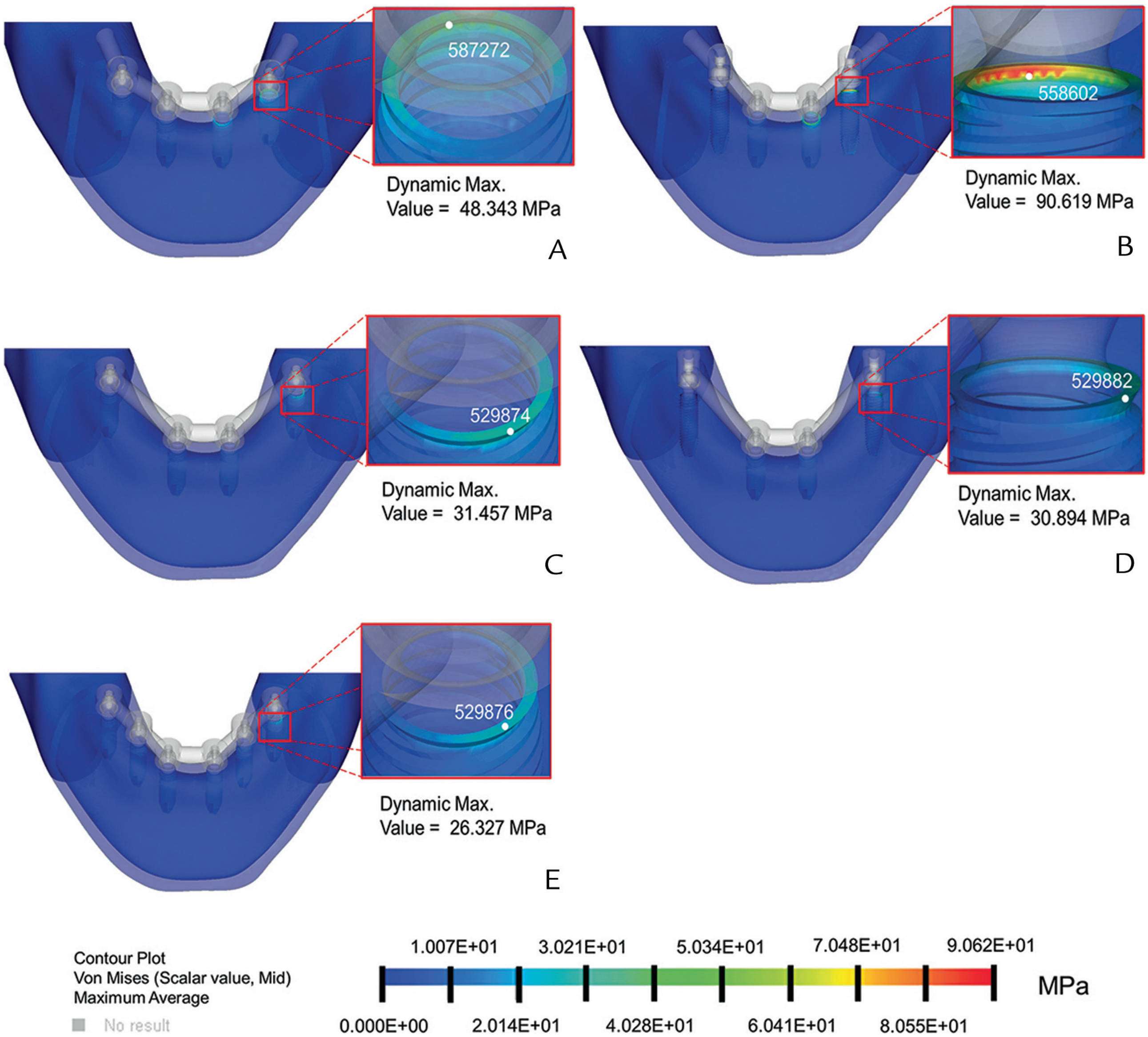

Figure 8. von Mises stress transferred to bone in critical mastication conditions, influence of clinical configuration. A, Model M1. B, Model M2. C, Model M3. D, Model M4. E, Model M5.

Table 8. Mean ±SD levels of stress and strain on system components in normal and critical mastication conditions

Half-Mandibular Loading	Model M1	Model M2	Model M3	Model M4	Model M5
Bone stress	10.9 ±2.38 MPa	26.6 ±7.1 MPa	12.1 ±3.5 MPa	11.4 ±3.4 MPa	9.3 ±2.0 MPa
Bone strain	800.0 ±17.0 με	1940 ±52.0 με	884.0 ±26.0 με	837.0 ±25.0 με	678.0 ±15.0 με
Dental implant stress	118.5 ±21.2 MPa	128.7 ±20.6 MPa	94.3 ±14.6 MPa	103.9 ±13.3 MPa	59.7 ±8.7 MPa
Screw stress	49.1 ±13.5 MPa	51.4 ±18.9 MPa	34.3 ±9.5 MPa	32.9 ±11.4 MPa	22.9 ±8.0 MPa
Bar-IOD stress	128.8 ±53.1 MPa	76.3 ±27.1 MPa	68.9 ±29.1 MPa	57.0 ±21.9 MPa	20.2 ±10.3 MPa
Molar 36 loading					
Bone stress	31.7 ±7.0 MPa	57.9 ±15.6 MPa	21.9 ±7.1 MPa	22.2 ±6.7 MPa	18.2 ±6.2 MPa
Bone strain	2314.0 ±508.0 με	4227.0 ±1142.0 με	1595.0 ±518.0 με	1619.0 ±487.0 με	1326.0 ±451.0 με
Dental implant stress	324.7 ±83.0 MPa	373.0 ±58.3 MPa	142.2 ±24.7 MPa	175.2 ±21.5 MPa	122.5 ±17.1 MPa
Screw stress	90.9 ±49.2 MPa	93.0 ±31.7 MPa	72.4 ±22.2 MPa	65.4 ±14.4 MPa	59.0 ±19.7 MPa
Bar-IOD stress	316.0 ±174.9 MPa	214.1 ±125.6 MPa	57.2 ±29.6 MPa	84.6 ±53.5 MPa	42.8 ±22.2 MPa

IOD, implant-supported overdenture; SD, standard deviation.

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