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RESEARCH AND EDUCATION

Evaluation of the effect of an offset implant configuration in the posterior maxilla with external hexagon implant platform: A 3-dimensional finite element analysis

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ABSTRACT

Statement of problem. Slight offset of the central implant in 3-unit implant-supported prostheses has been reported to improve biomechanical behavior. However, studies that assessed the effects of an offset implant configuration in the posterior maxilla are scarce.

Purpose. The purpose of this 3-dimensional (3D) finite element analysis was to assess the effects of splinting in 3-unit implant-supported prostheses with varying implant positions (straight-line or offset configuration) in terms of the stress/strain distribution on bone tissue and the stress distribution on abutment screws.

Material and methods. Three 3D models were used to simulate a posterior maxilla bone block (type IV): straight-line implants supporting single crowns (model M1), straight-line implants supporting 3-unit splinted fixed dental prosthesis (model M2), and an offset implant configuration supporting 3-unit splinted fixed dental prosthesis (model M3). The applied forces were 400 N axially and 200 N obliquely. The type of implant platform simulated was an external hexagon. von Mises stress on the abutment screws was measured, and the maximum principal stress and microstrain values were used to perform cortical bone tissue analysis. Analysis of variance (ANOVA) and the Tukey honest significant differences post hoc test were used to determine the significance of the results and interactions among the main variables (α=.05).

Results. In all models, oblique load increased the stress on abutment screws and bone tissue and the microstrain on bone tissue. Model M3 decreased the stress concentration on the abutment screws and bone tissue. With regard to microstrain distribution, model M3 had the smallest values, and M1 and M2 had similar values.

Conclusions. Splinting associated with an offset implant configuration was effective for decreasing the stress on abutment screws and bone tissue and the microstrain on bone tissue. (J Prosthet Dent 2017;118:363-371)

Before dental implants, removable partial denture prostheses were considered the best treatment option for extensive partial edentulism with no prospective terminal abutment tooth, such as in Kennedy class I and II scenarios.[1] However, dental implants offer a viable treatment option for managing clinical scenarios of both partial and complete edentulism.[2,3]

Different ways of rehabilitating patients with extensive partial edentulism with no prospective terminal abutment tooth have been described, mainly in the context of planning the placement of 3 implants to support the replacement of missing premolars and a molar, or a missing second premolar and 2 molars.[4,5] For these restorations, there are 2 ways to

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Clinical Implications

Splinting with an offset implant configuration improves the biomechanical behavior of 3-unit fixed dental prostheses. This type of implant placement may represent a good treatment option for the rehabilitation of the posterior maxilla.

place the implants: in a straight-line configuration or in an offset configuration.[4,6] Furthermore, the prostheses may be single units or splinted as a fixed dental prosthesis (FDP).[5] Weinberg and Kruger[7] suggested that slight displacement of the central implant relative to the lingual or buccal area (an offset configuration) could improve the biomechanical behavior of the restoration, and since that report, the effects of implant position have been evaluated in different biomechanical studies.[8-10] However, no consensus has been reached on the advantages of using an offset configuration, although some biomechanical studies have shown a slight improvement in bone stress distribution, mainly under oblique load.[4] Furthermore, the authors are unaware of published studies that have evaluated the biomechanical behavior of the offset implant placement on the posterior maxilla. Additionally, hygiene access may be impaired when an offset implant is placed because of the modification of the cervical contours of the prosthesis.

Clinicians are unclear as to whether the crowns in the posterior area should be splinted or not.[11,12] Some authors have suggested that, compared with single-unit crowns, a splinted prosthesis offers better stress distribution,[5,13] particularly in low-quality bone.[14] However, the use of single-unit crowns (not splinted) enables patients to maintain optimal oral hygiene, facilitates a better restoration fit, and is associated with better restoration emergence profiles and cervical contours.[15,16]

Bone quality may affect the survival rate of dental implants, as type IV bone (Lekholm and Zarb classification) is associated with a lower survival rate than type I, II, or III.[3,17] Therefore, the biomechanical behavior of different prostheses is particularly important for rehabilitating the posterior maxilla area in type IV bone, particularly in patients missing premolars and a molar or a second premolar and 2 molars, where 3 implants are placed.

Finite element analysis (FEA) enables simulation of a situation that would be impossible to perform in a clinical study.[18] Additionally, mathematical calculations can be used to predict unfavorable biomechanical situations for bone tissue and prosthetic components.[19] Therefore, FEA is considered a useful tool for studying stress distribution in implantology.[19,20]

The purpose of the present study was to assess the effects of splinting in 3-unit implant-supported prostheses with varied implant positions (a straight-line or offset configuration) on the stress/strain distribution on bone tissue and the stress distribution on abutment screws using 3-dimensional (3D) FEA. The null hypothesis was that these implant positions would not generate any significant differences in the biomechanical behavior of the models analyzed.

Table 1. Description of models

Implant	Model	Implant Position	Crown Design	Load	No. of Nodes/ Elements
EH (4.0×10 mm)	M1	Straight-line	Single-unit crown	Axial	1 238 344/ 890 640
				Oblique	
	M2	Straight-line	Splinted crowns	Axial	1 399 415/ 581 493
				Oblique	
	M3	Offset	Splinted crowns	Axial	953 290/ 591 677
				Oblique	

EH, external hexagon; M1, straight-line implants supporting single crowns; M2, straight-line implants supporting 3-unit splinted fixed dental prosthesis; M3, offset implant configuration supporting 3-unit splinted fixed dental prosthesis.

MATERIAL AND METHODS

Three 3D models were created to represent clinical situations (Table 1). Each model simulated a bone block (type IV) of the posterior maxillary segment (first premolar to right first molar) by varying the splinting and arrangement of the implants as follows: straight-line implants supporting single crowns (model M1), straight-line implants supporting 3-unit splinted FDP (model M2), and an offset implant configuration supporting 3-unit splinted FDP (model M3). The bone section was composed of trabecular bone in the center, surrounded by a 1-mm cortical bone layer obtained by decomposition of a computed tomography (sagittal section) of the first premolar to the right first molar with software (InVesalius; CTI Renato Archer) and surface simplification performed using software (Rhinoceros 3D v4.0; NURBS modeling for Windows [Microsoft Corp]; Robert McNeel & Associates).

The implant design was obtained by simplification of a 4.0×10 mm external hexagonal design (Conexão Sistemas de Protese Ltd). The positions of the implants in the straight-line models were simulated at a distance of 7 mm between the premolars, which was measured from center to center and a distance of 8.75 mm between the premolar and first molar.[21] In the offset implant configuration model, the intermediate implant, relative to the second premolar, was displaced by 1.5 mm in the buccal direction.[21-24] Furthermore, simulation of the customized implant abutment was the same in all models. Screw-retained metal-ceramic crowns were simulated in straight-line models, with single-unit

Table 2. Mechanical properties applied in finite element analysis

Structure	Elastic Modulus (GPa)	Poisson Ratio (ν)	References
Trabecular bone with low density (type IV bone)	1.10	0.30	Sevimay et al.[28] 2005
Cortical bone	13.7	0.30	Sertgöz[27] 1997
Titanium	110.0	0.35	Sertgöz[27] 1997
Ni-Cr alloy	206.0	0.33	Anusavice and Hojjatie[25] 1987
Feldspathic porcelain	82.8	0.35	Eraslan et al[26] 2005

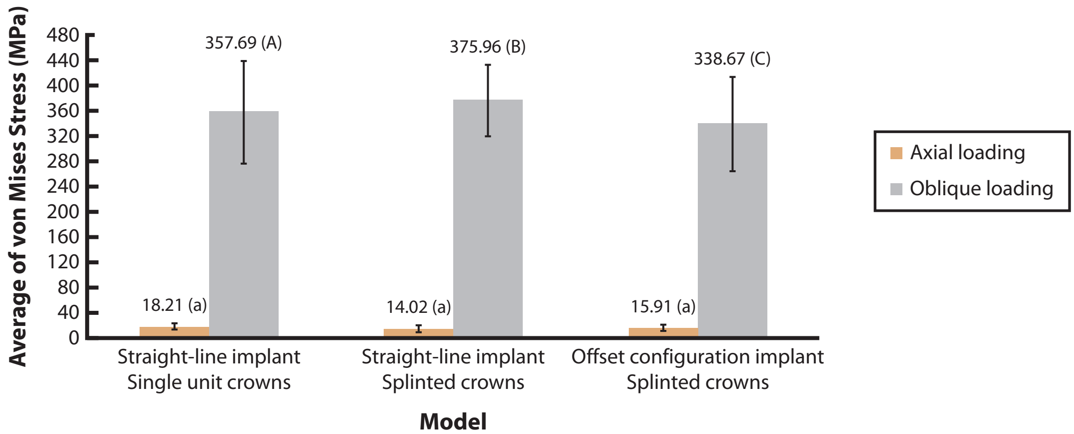

Figure 1. Mean ±SD values of abutment screw von Mises stress under axial and oblique loads. Different uppercase and lowercase letters indicate significant differences (*P*<.05).

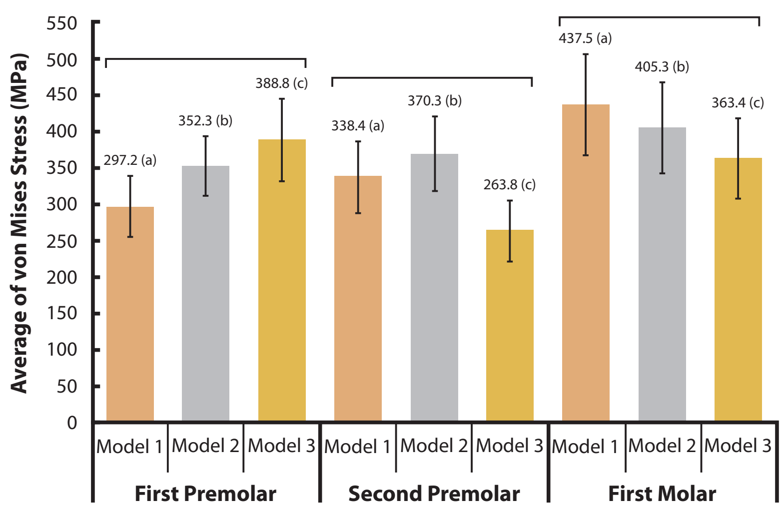

Figure 2. Mean ±SD values of abutment screw von Mises stress for each implant under oblique load. Different lowercase letters indicate significant differences (*P*<.05).

and splinted FDPs. Implants, abutments, crowns, and abutment screws were simplified using design (SolidWorks 2010; SolidWorks Corp) and 3D computer graphics software (Rhinoceros v4.0; NURBS modeling for Windows [Microsoft Corp]; Robert McNeel & Associates). Finally, all geometries were exported to discretization in the finite element program (FEMAP v11.1.2; Siemens PLM Software Inc).

The FEMAP 11.1.2 software was used to generate 3D models of the preprocessing and postprocessing stages. Meshes with tetrahedral parabolic solid elements were generated in the preprocessing stage. Moreover, the mechanical properties of each simulated material were attributed to the meshes using values from previous studies (Table 2).[25-28] All materials were considered isotropic, homogeneous, and linearly elastic. The numbers of nodes and elements are presented in Table 1. During the postprocessing stage, maps created from mathematical calculations generated by FEA solver software (NEi Nastran v11.1; Noran Engineering Inc)

Table 3. Abutment screw von Mises stress means ±SD

Model	Loading	Implant Position*	Mean ±SD
M1	Axial	1°PM	11.57 ±1.31
M1		2°PM	21.07 ±2.39
M1		1°M	22.01 ±2.20
M2		1°PM	7.85 ±0.71
M2		2°PM	14.02 ±1.46
M2		1°M	20.31 ±2.41
M3		1°PM	12.02 ±1.74
M3		2°PM	13.20 ±0.96
M3		1°M	22.53 ±2.29
M1	Oblique	1°PM	297.15 ±41.97
M1		2°PM	338.41 ±49.25
M1		1°M	437.53 ±69.95
M2		1°PM	352.30 ±41.12
M2		2°PM	370.32 ±51.14
M2		1°M	405.28 ±62.46
M3		1°PM	388.85 ±55.69
M3		2°PM	263.80 ±41.60
M3		1°M	363.38 ±54.71

M1, straight-line implants supporting single crowns; M2, straight-line implants supporting 3-unit splinted fixed dental prosthesis; M3, offset implant configuration supporting 3-unit splinted fixed dental prosthesis. *1°PM, first premolar; 2°PM, second premolar; 1°M, first molar.

were read and plotted, as described in further detail subsequently.

In the preprocessing stage, the abutment/implant contact was assumed to be symmetrical, and all other contacts were assumed to be symmetrically welded. The boundary conditions were fixed in axes x, y, and z, simulating fixation of the maxilla to the facial skeleton. The applied forces were 400 N axially, with 50 N at each cusp tip and 200 N obliquely, with 50 N at each lingual cusp tip.

All FEAs were performed using FEA solver software (NEi Nastran v11.1; Noran Engineering Inc). The processing analysis was performed using a workstation (Hewlett-Packard Development Co) with the following characteristics: Intel Xeon Processor X3470, 16 GB RAM, and 2 TB of storage. Results were exported to FEA software (FEMAP v11.1.2; Siemens PLM Software Inc) to create graphic visualizations of stress/strain on bone tissue and abutment screws. von Mises analysis was used to assess the stress distribution in abutment screws, and quantitative analysis was performed as it is adequate for the analysis of ductile material.[19]

Maximum principal stress was used to assess the stress on cortical bone tissue by means of qualitative analysis, as it provides compression (negative values) and tension (positive values) values.[20,29] Additionally, microstrain ($\mu\varepsilon$) analysis was used to assess deformation around the cortical bone tissue.[19] Both quantitative and qualitative analyses were performed to obtain values to compare with the resorption risk scale described by Frost.[30] The unit of measure used for von Mises stress and the maximum principal stress was megapascal (MPa), whereas microstrain was determined by a deformation unit and thus is dimensionless.

The quantitative data pertaining to stress on abutment screws were analyzed using 2-way analysis of variance (ANOVA), followed by the Tukey honest significant differences post hoc test (α=.05). The quantitative data pertaining to microstrain on bone tissue were analyzed using 3-way ANOVA, followed by the Tukey honest significant differences post hoc test. Statistical analysis was performed using statistical software (Sigma Plot v12.0; Systat Software Inc).

RESULTS

von Mises stress values were similar in all models under axial load (M1 versus M2: P=.755; M1 versus M3: P=.918; M3 versus M2: P=.946) (Fig. 1). Compared with axial load, oblique load increased the stress in all models (P<.001) (Fig. 1). In this context, an offset implant configuration with splinting (M3) decreased the stress on abutment screws (M3 versus M1, P=.003; M3 versus M2, P<.001) (Fig. 1). Furthermore, splinting had the beneficial effect of dissipating the stress on the abutment screws used to retain the molar crown to the other abutment screws (Fig. 2), although on average, M2 exhibited significantly more stress than M1 (M1 versus M2: P=.005) (Fig. 1), see also mean and standard deviation values for von Mises stress on abutment screws in Table 3.

An offset implant configuration associated with splinting (M3) caused changes in the stress distribution pattern (Fig. 3). The highest area of compression and tension stresses was observed in the first molar region in M3 compared with M1 and M2 under axial load. Compared with M1 under oblique load, M2 and M3 exhibited a modified pattern of stress distribution. An offset implant configuration associated with splinting (M3) decreased the tension stress area in the lingual region (the first molar), whereas for M1 and M2, the tension stress area extended to the superior portion of the cortical bone tissue with a higher stress area (13.33 MPa to 22.33 MPa) in the first molar for M1 (Fig. 4). Furthermore, M3 had a higher tension stress area in the lingual region of the first premolar.

M3 exhibited the lowest microstrain values under axial load (M1 versus M3, P<.001; M2 versus M3, P=.006) (Figs. 5, 6). M1 and M2 exhibited similar biomechanical behavior (P=.669).

Compared with axial load, oblique load caused a larger area of microstrain in the buccal region of the cortical bone in all models (P<.001) (Fig. 7). In this context, M1 and M2 had similar biomechanical behavior (P=.284), with a slight increase in microstrain for M1, and the smallest microstrain values were observed in M3 (M1

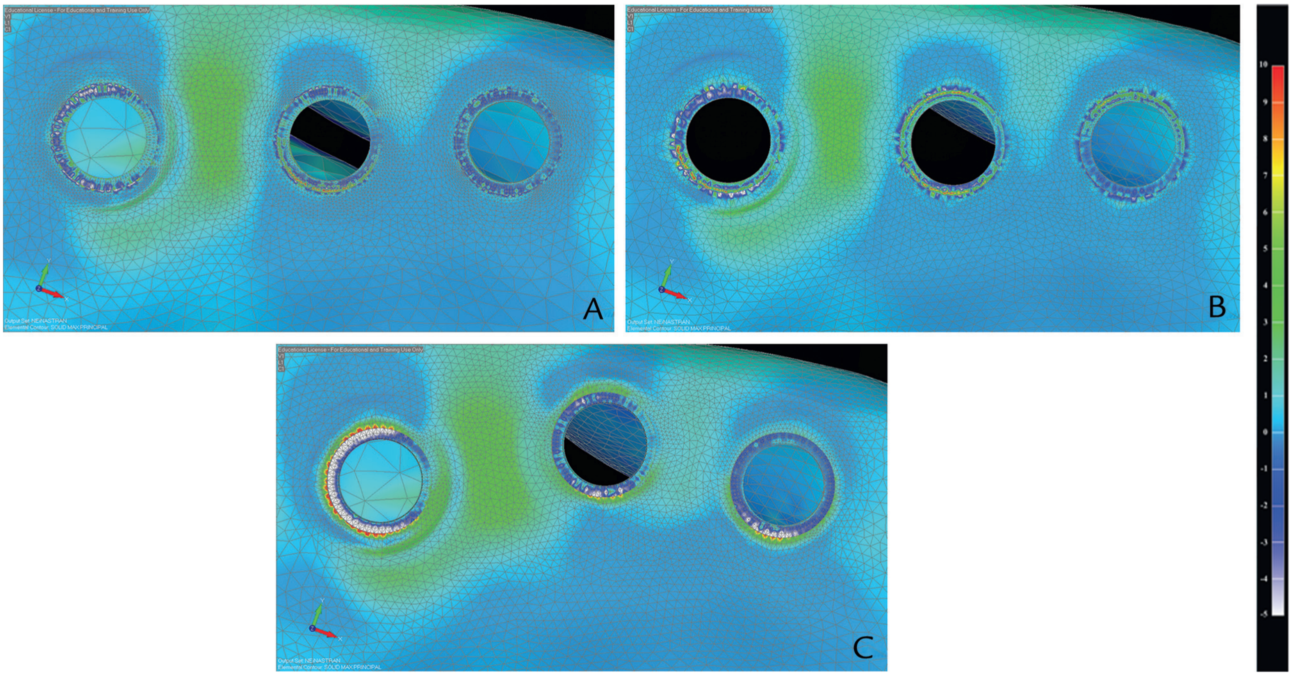

Figure 3. Maximum principal stress on cortical bone; axial load, occlusal view. A, Model 1, straight-line implants supporting single crowns. B, Model 2, straight-line implants supporting 3-unit splinted fixed dental prosthesis. C, Model 3, offset implant configuration supporting 3-unit splinted fixed dental prosthesis.

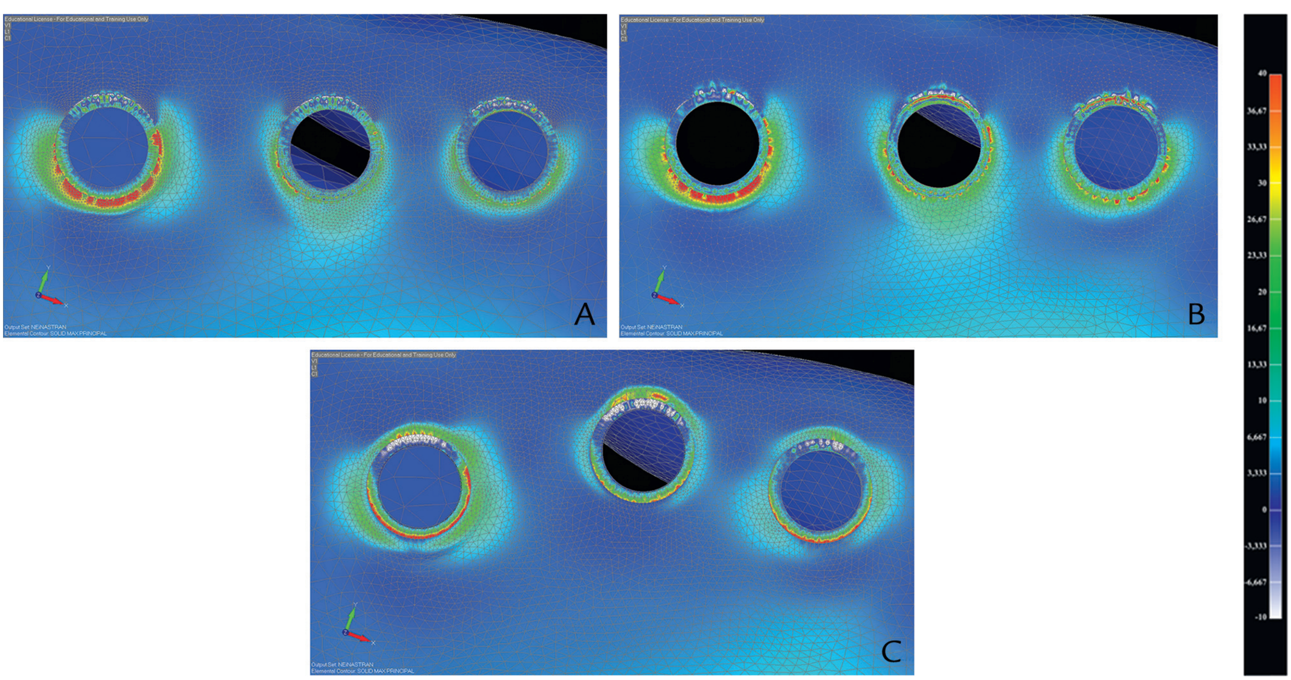

Figure 4. Maximum principal stress on cortical bone; oblique load, occlusal view. A, Model 1, straight-line implants supporting single crowns. B, Model 2, straight-line implants supporting 3-unit splinted fixed dental prosthesis. C, Model 3, offset implant configuration supporting 3-unit splinted fixed dental prosthesis.

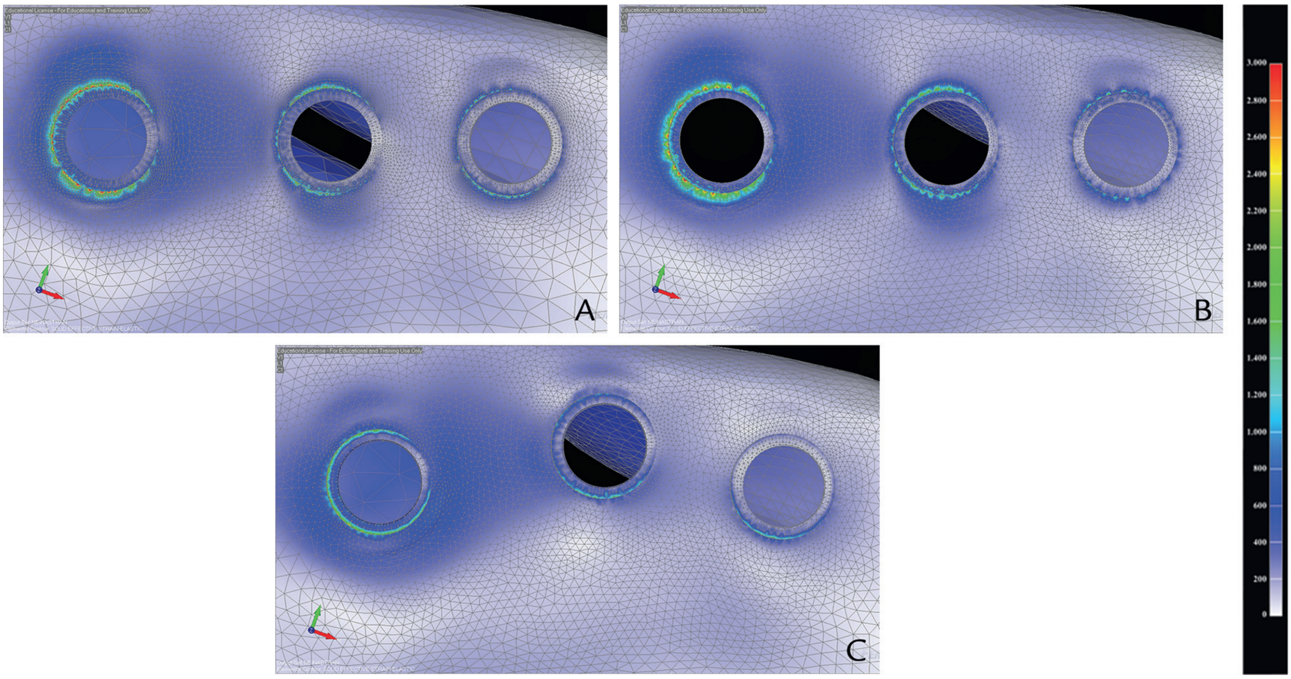

Figure 5. Microstrain on cortical bone; axial load, occlusal view. A, Model 1, straight-line implants supporting single crowns. B, Model 2, straight-line implants supporting 3-unit splinted fixed dental prosthesis. C, Model 3, offset implant configuration supporting 3-unit splinted fixed dental prosthesis.

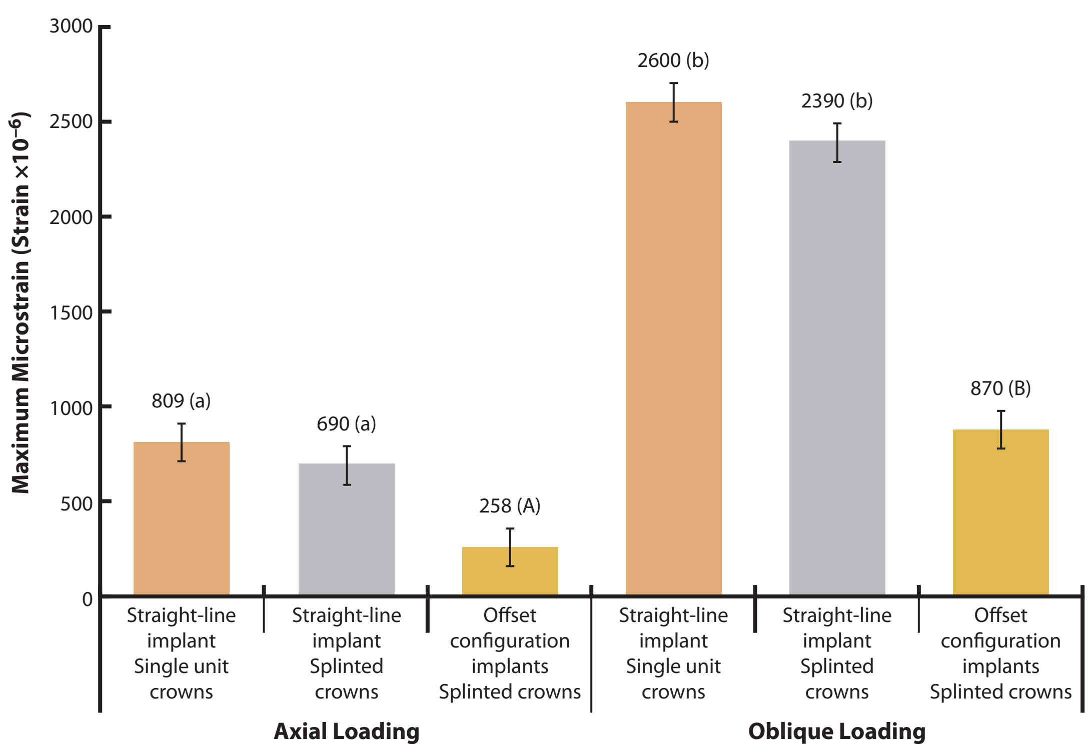

Figure 6. Mean ±SD values for microstrain on cortical bone tissue under axial and oblique load. Different uppercase and lowercase letters indicate significant differences (*P*<.05).

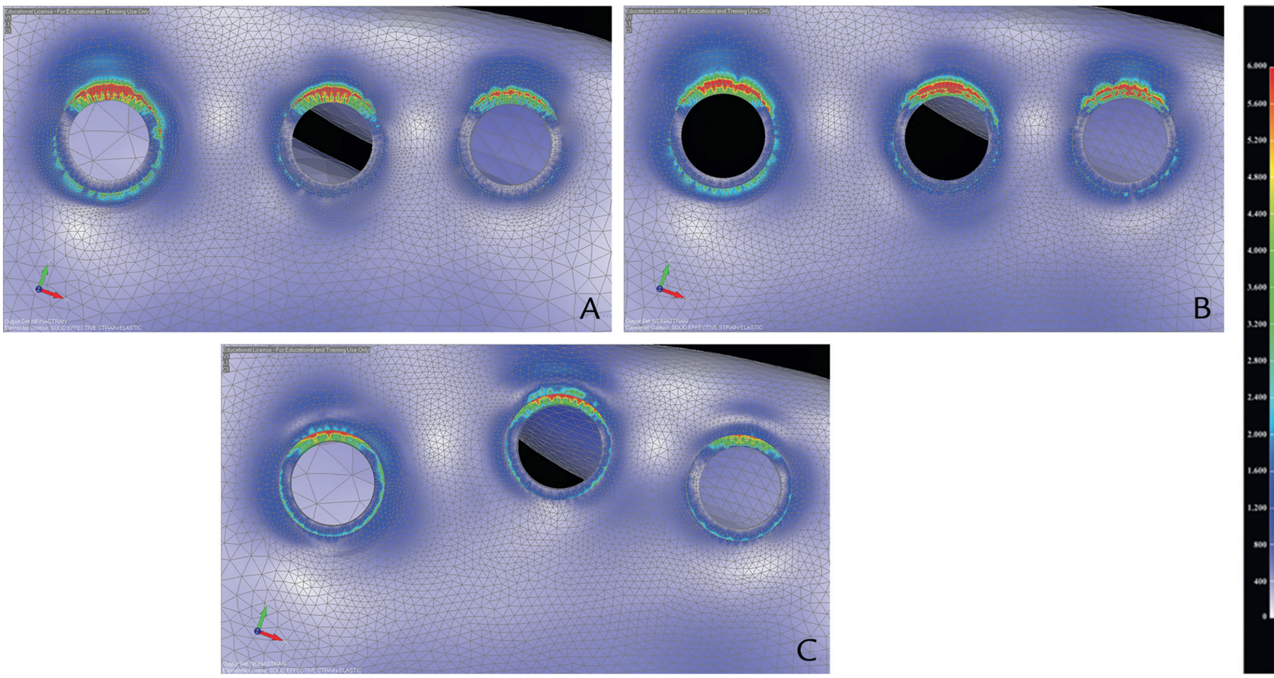

Figure 7. Microstrain on cortical bone; oblique load, occlusal view. A, Model 1, straight-line implants supporting single crowns. B, Model 2, straight-line implants supporting 3-unit splinted fixed dental prosthesis. C, Model 3, offset implant configuration supporting 3-unit splinted fixed dental prosthesis.

versus M3, $P<.001$; M2 versus M3, $P<.001$) (Figs. 6, 7). Mean values for cortical bone tissue, microstrain, under axial load are shown in Table 4 and in Table 5 under oblique load.

DISCUSSION

The null hypothesis was rejected because splinting associated with an offset implant configuration had a different biomechanical behavior in the analyzed models.

In the present study, the bone microstrain values under axial load were within the proposed limits of the mechanostat hypothesis described by Frost[30] (3000 με); however, these values exceeded the bone's operational microdamage threshold range, reaching more than 6000 με.[30] In the present study, bone tissue was considered isotropic, linear, and homogeneous under static linear FEA, which is similar to previous studies,[31,32] and these factors might have contributed to these high values. Thus, the data obtained in this study should be seen as representing unfavorable clinical outcomes and should be cautiously extrapolated to the clinical setting.

Oblique load increased the stress on abutment screws and stress/strain on bone tissue. This is consistent with the findings of recent studies that have reported increases in stress at the implant/abutment interface,[19] abutment screw,[32] and bone tissue[29,20] under oblique loads. The results of this study indicated a beneficial effect of splinting when associated with an offset implant configuration to reduce overload, mainly on the prosthetic screws. Thus, abutment screw loosening and/or fracture is less likely when splinting is performed in the tripoidal position (M3), a desirable situation in rehabilitation with external hexagon implants.

Regarding the stress and strain distribution on cortical bone tissue, rehabilitation of the posterior maxilla with single crowns (M1) exhibited similar results compared with straight-line splinted FDPs (M2), consistent with the findings of Mendonça et al,[11] who reported similar marginal bone loss between single and splinted crowns between 3 and 16 years. In contrast, Nissan et al[33] suggested that splinting may provide favorable biomechanical behavior but only for short implants. Therefore, the similar biomechanical effects on the cortical bone tissue observed for single crowns (M1) and straight-line splinted FDPs (M2) in the present study could be justified by the use of a conventional length (10 mm). It has been suggested that the effect of splinting is more beneficial to the stress distribution on bone tissue when it is possible to plan the use of longer length implants associated with short implants.[5]

In the current study, the offset implant configuration decreased the stress on abutment screws and the microstrain on cortical bone tissue around the implants. Some previous studies have reported the advantages of using the offset implant configuration to decrease stress on bone around implants,[8,24,34] but the authors are

Table 4. Cortical bone tissue microstrain under axial load means ±SD

Model	Implant Position	Region	Mean ±SD
M1	1°PM	Buccal	503 ±101
		Mesial	272 ±106
		Lingual	895 ±187
		Distal	395 ±160
	2°PM	Buccal	1120 ±262
		Mesial	85.2 ±22
		Lingual	876 ±285
		Distal	577 ±210
	1°M	Buccal	1940 ±422
		Mesial	262 ±68
		Lingual	1380 ±673
		Distal	1480 ±617
M2	1°PM	Buccal	563 ±129
		Mesial	258 ±88
		Lingual	585 ±158
		Distal	263 ±88
	2°PM	Buccal	993 ±163
		Mesial	189 ±53
		Lingual	945 ±157
		Distal	445 ±146
	1°M	Buccal	1500 ±276
		Mesial	375 ±82
		Lingual	1230 ±325
		Distal	1200 ±378
M3	1°PM	Buccal	113 ±27
		Mesial	555 ±64
		Lingual	249 ±99
		Distal	421 ±89
	2°PM	Buccal	244 ±58
		Mesial	298 ±30
		Lingual	232 ±83
		Distal	194 ±83
	1°M	Buccal	113 ±27
		Mesial	197 ±32
		Lingual	255 ±99
		Distal	197 ±25

1°PM, first premolar; 2°PM, second premolar; 1°M, first molar; M1, straight-line implants supporting single crowns; M2, straight-line implants supporting 3-unit splinted fixed dental prosthesis; M3, offset implant configuration supporting 3-unit splinted fixed dental prosthesis.

Table 5. Cortical bone tissue microstrain under oblique load means ±SD

Model	Implant Position	Region	Mean ±SD
M1	1°PM	Buccal	4830 ±1050
		Mesial	1020 ±272
		Lingual	969 ±154
		Distal	759 ±189
	2°PM	Buccal	7810 ±1902
		Mesial	831 ±331
		Lingual	852 ±222
		Distal	1190 ±200
	1°M	Buccal	8760 ±2198
		Mesial	2960 ±1108
		Lingual	2030 ±864
		Distal	1750 ±443
M2	1°PM	Buccal	6020 ±1671
		Mesial	1240 ±221
		Lingual	1160 ±248
		Distal	719 ±126
	2°PM	Buccal	6460 ±1368
		Mesial	1130 ±248
		Lingual	973 ±127
		Distal	1210 ±199
	1°M	Buccal	6690 ±1811
		Mesial	1470 ±235
		Lingual	1900 ±403
		Distal	1410 ±199
M3	1°PM	Buccal	910 ±511
		Mesial	890 ±273
		Lingual	548 ±247
		Distal	542 ±77
	2°PM	Buccal	1590 ±372
		Mesial	857 ±395
		Lingual	264 ±178
		Distal	940 ±405
	1°M	Buccal	1150 ±433
		Mesial	1130 ±382
		Lingual	542 ±269
		Distal	1080 ±393

1°PM, first premolar; 2°PM, second premolar; 1°M, first molar; M1, straight-line implants supporting single crowns; M2, straight-line implants supporting 3-unit splinted fixed dental prosthesis; M3, offset implant configuration supporting 3-unit splinted fixed dental prosthesis.

unaware of any studies that have evaluated the abutment screws in this context using FEA. Furthermore, bone availability is an essential factor when the offset implant configuration is used. Finally, randomized controlled trials are necessary to confirm the advantages of using this implant position.

The investigation of only 1 offset distance from the central implant (1.5 mm) is a limitation of the present study. Sütpideler et al[24] suggested that a greater distance from the central position of the implant is more beneficial in terms of stress distribution on the bone tissue; however, that study did not use dental implants placed in the maxilla. This variable should be evaluated in further studies.

Several studies have evaluated the offset implant configuration in mandibular bone tissue by FEA,[10,24,35-37] but the authors are unaware of corresponding reports investigating the maxilla. The current study's results may promote a better understanding of this variable in poor quality bone, enabling physicians to improve rehabilitation planning involving the posterior regions of the maxilla.

CONCLUSIONS

Within the limitations of this finite element study, the following conclusions were drawn:

1. Splinting associated with an offset implant configuration was effective in decreasing the stress on abutment screws and bone tissue;
2. Splinting associated with an offset implant configuration decreased the microstrain on cortical bone tissue.

3. Oblique load increased the stress on abutment screws and increased the stress and strain on cortical bone tissue.

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