Loading of a Single Implant in Simulated Bone

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This study investigated the effect of occlusal design on the strain developed in simulated bone of implant-supported single crown models. Triaxial strain gauges were attached at the cervical area of each model. Occlusal design, load location, and magnitude were examined to determine the maximum axial principal strains (με) of four occlusal designs: 30-degree cusp inclination with 4- and 6-mm occlusal table dimensions and a 10-degree cusp inclination with 4- and 6-mm occlusal table dimensions. Statistical differences were found for peak average maximum principal strains between each occlusal design when the applied load was directed along the central fossa and 2 mm buccal to the central fossa along the inclined plane, with strain gauges attached at the cervicobuccal ($P < .001$) and cervicolingual ($P \leq .001$) aspects. In all loading conditions, the 30-degree cusp inclination and 6-mm occlusal table dimension consistently presented the largest strains compared with the other occlusal designs. A reduced cusp inclination and occlusal table dimension effectively reduced experimental bone strain on implant-supported single crowns. The occlusal table dimension appeared to have a relatively more important role than cusp inclination. *Int J Prosthodont 2011;24:140–143.*

Studies report promising results and justification for occlusal design guidelines for tooth- and implant-supported single crowns. However, there is no consensus on a superior occlusal design. A recent systematic review and meta-analysis indicated that single-implant restorations have a higher risk of failure, and better outcomes are achieved using conventional loading as opposed to immediate loading.[1]

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The purpose of this study was to compare simulated bone strains of implant-supported second premolar crowns under controlled experimental conditions with four occlusal designs: *(1)* a 30-degree cusp inclination and 6-mm occlusal table, *(2)* a 30-degree cusp inclination and 4-mm occlusal table, *(3)* a 10-degree cusp inclination and 6-mm occlusal table, and *(4)* a 10-degree cusp inclination and 4-mm occlusal table.

Materials and Methods

Each implant was placed in a simulated bone model of heat-cured acrylic resin. Regular-platform, 3.75-mm diameter, 10-mm long Brånemark Mk III implants (Noble Biocare) were placed vertically in the acrylic resin molds with a regular-platform titanium provisional abutment (Noble Biocare), onto which a ceramic crown (VITABLOCS Mark II, Sirona Dental Systems) was cemented.

Three-element 45-degree rectangular stacked rosette strain gauges of 120 Ω (model WA-06-030 WR-120, Vishay Micro-Measurements) were cemented at the middle of the cervical area of the buccal and lingual aspects of the bone simulation models. Static loads of 50, 100, 150, 200, and 250 N were applied for

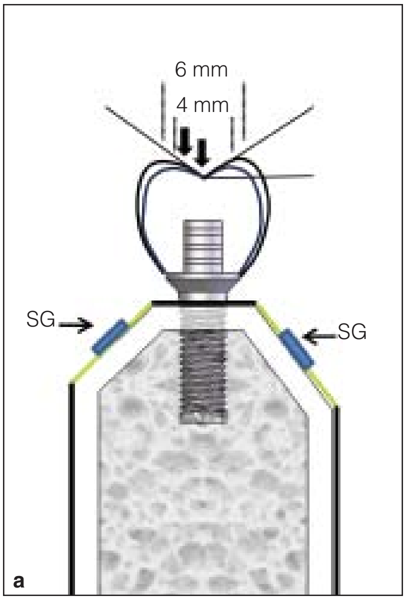
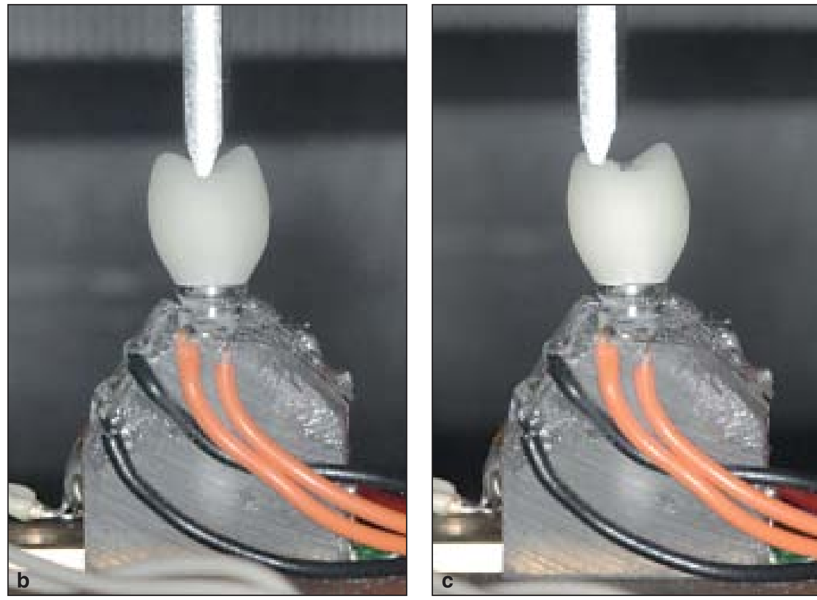


Fig 1a Experimental design for an implant-supported single crown with strain gauges (SG) attached at the buccal and lingual aspects.



Figs 1b and 1c The applied forces were loaded at two sites: **(b)** the central fossa area and **(c)** 2 mm buccal to the central fossa.

15 seconds at two loading sites (the central fossa and 2 mm buccal to the central fossa along the inclined plane [Fig 1]) using a computer-controlled precision universal testing machine (Instron 8874) in the load control mode. A series of 5 axial forces was applied 10 times to each occlusal-design specimen.

Study variables were compared and analyzed using analysis of variance, and a significance level of 5% ($P < .05$) was applied throughout the analyses.

Results

The results listed in Table 1 show a significant difference in microstrain values between designs 1, 2, 3, and 4 and applied axial loads at 2 mm buccal to the central fossa on the cusp incline with strain gauges attached on the buccal aspect ($P < .001$) compared to the same arrangement of axial loading at 2 mm buccal on the cusp incline but with strain gauges attached on the lingual aspect ($P \leq .001$). The 2-mm-buccal–loaded specimens had significantly greater maximum principal strains compared with central fossa–loaded specimens ($P < .001$). The greatest maximum principal strain was found in design 1, and the lowest was recorded for design 4.

Discussion

The model was designed to approximate the clinical situation of implant-supported second premolar crowns. It was not possible to simulate the morphology and properties of bone surrounding dental implants. However, the rationale for investigating occlusal design was to determine an optimum design. The calculated maximum principal strains were compared under controlled conditions for each occlusal design.

Mathematic formulae and vector force analyses, as shown in Fig 2, were applied to account for axial and eccentric stresses, as well as the inclined surface. With the 20-degree increase in cusp inclination, there was an average 30% and 50% increase in horizontal forces and torque production, respectively, for the different loading conditions (Table 2). As cusp inclination and occlusal table dimension increase, a resultant line of force is produced and the distance from the center of the third implant thread to the line of force intensifies. As a result, if cusp inclination and occlusal table dimension increase, this creates flexure, and the more lateral the contact on the tooth cusp, the greater the contact inclined flexure. This may cause both compressive and bending responses

Table 1 Mean Maximum Principal Strains of the Four Different Occlusal Designs with Different Loading and Strain Gauges Attached on the Buccal and Lingual Aspects

Occlusal design/force (N)	2 mm buccal loading on inclined plane*				Central fossa loading*			
	Cervicobuccal area†		Cervicolingual area‡		Cervicobuccal area		Cervicolingual area	
	Strain (με)†	SD	Strain (με)‡	SD	Strain (με)	SD	Strain (με)	SD
1								
50	163.43	16.60	191.12	24.11	22.37	5.80	37.36	6.22
100	472.98	21.30	361.38	33.20	68.94	11.35	83.14	13.16
150	774.76	44.11	501.37	37.19	125.42	18.64	141.81	25.67
200	1,087.76	44.34	653.46	31.60	178.12	19.07	185.78	23.71
250	1,258.99	14.54	725.94	34.96	221.44	21.21	245.46	33.04
2								
50	42.57	5.93	51.01	7.88	14.58	11.14	30.39	10.96
100	93.10	5.69	94.11	5.09	22.72	13.05	44.70	7.77
150	146.44	9.90	135.24	7.90	31.12	22.34	61.47	13.03
200	192.66	8.82	174.44	7.58	44.71	28.29	79.14	12.03
250	231.85	6.10	209.37	9.21	67.73	29.49	101.14	5.54
3								
50	48.15	3.28	38.04	7.45	41.80	24.86	46.85	30.88
100	104.70	3.31	86.29	18.19	44.31	8.76	75.82	26.56
150	167.28	5.73	135.41	18.05	73.17	13.46	91.24	42.55
200	240.84	5.84	188.34	34.87	109.85	16.78	103.49	40.08
250	316.82	13.71	220.59	29.18	155.34	18.20	115.97	40.24
4								
50	5.10	0.83	47.49	8.87	18.11	5.15	69.62	24.67
100	32.98	2.37	80.55	9.59	42.98	5.23	103.16	37.43
150	68.85	2.12	110.76	10.68	71.52	4.38	113.66	40.06
200	112.58	3.50	144.85	14.96	105.10	11.82	172.38	68.82
250	156.98	4.47	200.09	29.53	141.39	14.87	203.89	57.52

SD = standard deviation.
*F = 29.782; applied load at 2 mm buccal on the inclined plane and applied load at the central fossa ($P < .001$, univariate test).
†F = 4,032.91; occlusal design: design 1 and design 2 ($P < .001$), design 1 and design 3 ($P < .001$), design 1 and design 4 ($P < .001$), design 2 and design 3 ($P < .001$), design 2 and design 4 ($P < .001$), design 3 and design 4 ($P < .001$) (post hoc test).
‡F = 677.971; occlusal design: design 1 and design 2 ($P < .001$), design 1 and design 3 ($P < .001$), design 1 and design 4 ($P < .001$), design 2 and design 3 ($P < .001$), design 2 and design 4 ($P < .001$), design 3 and design 4 ($P < .001$) (post hoc test).

on the crowns and implant components, which may lead to fracture. The load concentration in the surrounding coronal bone may also predispose the implant site to bone loss.

The results and mathematic analyses were in agreement with other studies,[2,3] which recommended that to decrease bending moments created within the implant, the optimal transfer of vertical occlusal load is along the implant's long axis. By centering the occlusion and reducing the occlusal table dimension, the lever arm is reduced. Reduced inclination of tooth cusps and a narrow occlusal table are also recommended by other studies.[4,5] The maximum principal strains were higher in designs 1 and 3 (both of which had 6-mm occlusal table dimensions) irrespective of cusp inclination, as reported by Morneburg and Pröschel.[6]

Although physical and mathematic modalities are used to simulate occlusal loading, there are no studies that specifically identify a clinically relevant risk for a particular occlusal design. Nevertheless, an increase in cusp inclination and occlusal table dimension creates flexure loads in function over the strain range of 50 to 1,500 με.[7]

Fig 2 Diagram showing the dimensions of the components of the implant-supported crown to calculate force and torque at the implant level. Fx1 = force along the cusp line; Fx2 = horizontal force; Fy = nonaxial force.

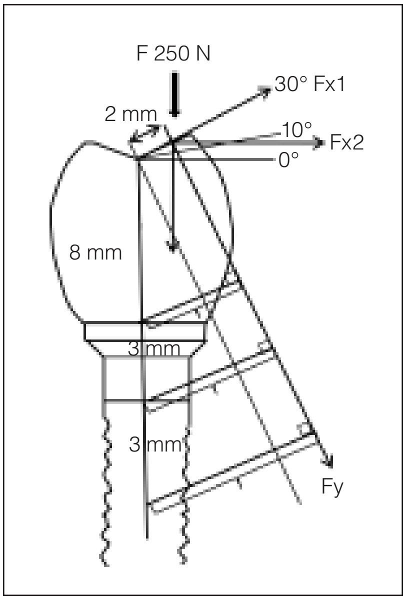


Table 2 Comparison of 30-Degree and 10-Degree Cusp Inclinations in Relation to Horizontal Forces, Nonaxial Forces, and Torque Production*

	30-degree cusp inclination			10-degree cusp inclination		
Occlusal loading force (N)	Horizontal force (N)	Nonaxial force (N)	Magnitude of torque (Nm)	Horizontal force (N)	Nonaxial force (N)	Magnitude of torque (Nm)
50	28.87	43.30	0.40	8.82	49.24	0.22
100	57.74	86.60	0.81	17.63	98.48	0.44
150	86.61	129.90	1.21	26.45	147.72	0.66
200	115.47	173.20	1.61	35.27	196.96	0.88
250	144.34	216.50	2.02	44.08	246.20	1.10

*Law of sines ($F\cos\theta = Fx$; $F\sin\theta = Fy$) was applied to determine the horizontal force and torque differences between 30-degree and 10-degree cusp inclinations at the implant level.

Conclusion

A reduced cusp inclination and occlusal table dimension effectively reduced bone strain on implant-supported single crowns in the laboratory model. The occlusal table dimension appeared to have a relatively more important role than cusp inclination, although cusp inclination was also an influencing factor.

Acknowledgments

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