Short Communication

Estimation of Functional Load Direction to an Implant Using Normal Lines on the Superstructure Occlusal Surface

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This study was designed to test the hypothesis that normal lines on the occlusal surface of a superstructure allow estimation of the functional load direction to an implant. Micro-occlusal surface data were obtained using a 3-dimensional laser scanner to identify the normal lines, and strains on the abutment surface were measured with strain gauges under static load using an in vitro model. Measurements were repeated following alterations of the occlusal surface cusp angle. Statistically significant correlations were found between the 2 measurements ($P < .05$), suggesting that normal lines on the occlusal surface can be used to estimate the load direction to an implant. *Int J Prosthodont 2007;20:235–238.*

According to the theory of physics, 2 kinds of stresses—normal stress and shear stress—are exerted on the microflat plane of a certain surface as long as the structure does not rotate or translate. The occlusal surface consists of numerous small curved surfaces, which can be subdivided into microflat surfaces. Forces are most effectively supported when they are applied perpendicularly to each flat surface, ie, in the normal line direction. Conversely, it can be hypothesized that the resultant force may be estimated from the sum of the normal vectors of the occlusal surface.

The present study was designed to test this hypothesis using an in vitro implant and superstructure model.

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Materials and Methods

A standard implant analog (3.75 mm diameter, BIOMET/3i) was embedded into a plaster cast, and a preparable abutment (Prep title, BIOMET/3i) was connected. On the surfaces of the abutment (buccal, lingual, distal, and mesial sides), 4 strain gauges were attached at right angles to each other according to a previous report.[1] A single first molar crown was fabricated using palladium-gold alloy and temporarily cemented onto the abutment.

A vertical force of 50 N was applied to the occlusal surface using a 6-mm-diameter stainless-steel ball with a 2-mm-thick ethyl vinyl acetate sheet to simulate resilient food mastication (Fig 1). The recordings were repeated 10 times after alteration of the cusp angle from 150 to 140 degrees and from 140 to 130 degrees. The differences between the strain data for the buccolingual and mesiodistal directions were calculated.

The occlusal surface morphology of the crown was analyzed and the normal lines were obtained using a 3-dimensional laser scanner (Surflaser, Unisn) and software (UGS, PLM Solutions) (Fig 2).[2] The normal line inclination was classified into the following 3 directions according to a reference plane: *(1)* x-axis angle in the

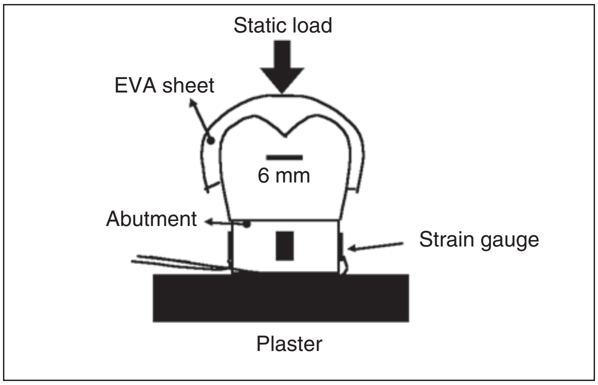

Fig 1 Diagram of the strain gauge recordings. EVA = ethyl vinyl acetate.

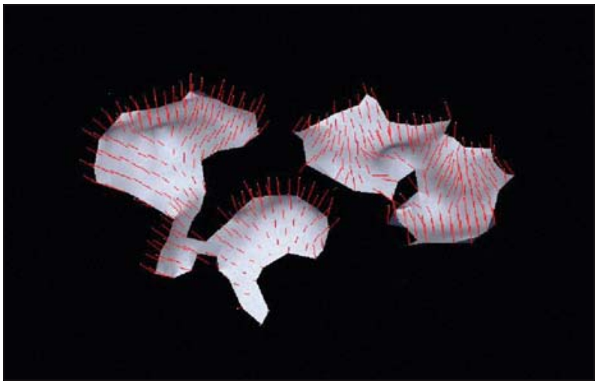

Fig 2 Example of the normal line distribution on an occlusal surface.

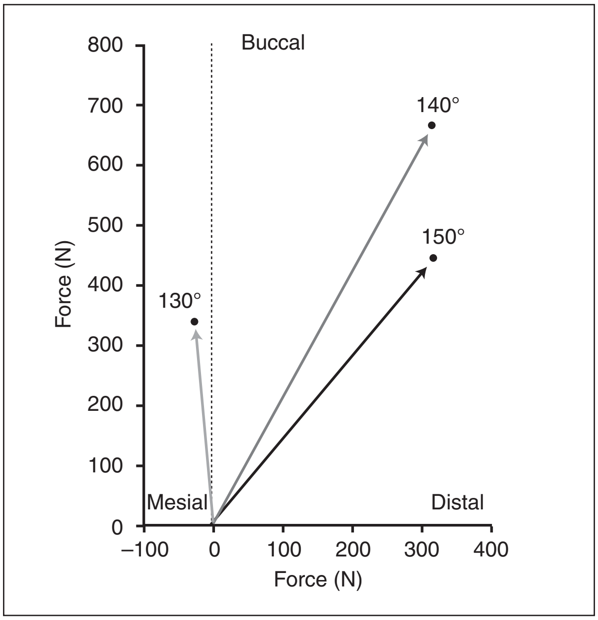

Fig 3a Direction of the resultant force estimated by the normal distribution.

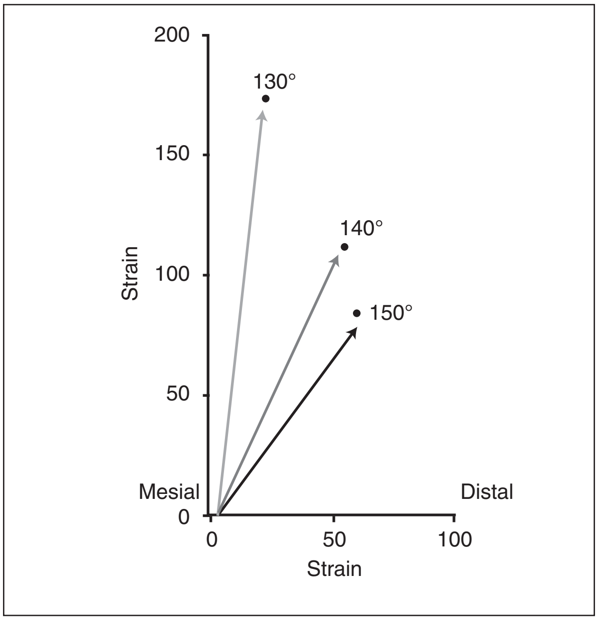

Fig 3b Direction of the resultant force estimated by strain gauge outputs.

mesiodistal direction where 0 and 180 degrees indicated the mesial and distal directions, respectively; *(2)* y-axis angle in the buccolingual direction where 0 and 180 degrees indicated the lingual and buccal directions, respectively; and *(3)* z-axis angle in the vertical direction. The x- and y-axes angles were computed using the coordinates of the starting and terminal points of the normal lines. The table of the loading machine was designated the reference plane, while the center of the implant was the zero point for the x- and y-axes. Statistical analysis was performed using Pearson correlation coefficient analysis (SPSS Software, SPSS) of the number of normal lines and obtained strains ($P < .05$). A comparison of the force directions was also carried out between the normal line distributions and resultant strains.

Results

Table 1 shows the distribution of the normal line numbers in each 10-degree increment in the x-y plane, in which the normal lines were mostly concentrated in the distal and buccal directions. Table 2 shows the normal line numbers in each 10-degree increment with the weighting factor of distance from the zero point and the resultant strains on the implant, where positive values indicate the distal and buccal directions as shown in Figs 3a and 3b. Both sets of results indicate that the direction of the resultant force was in the distal and buccal directions and gradually shifted mesially along with alterations to the cusp angle.

Table 1 Distribution of the Normal Line Numbers in Each 10-Degree Increment in the x-y Plane

y/x	0–10	10–20	20–30	30–40	40–50	50–60	60–70	70–80	80–90	90–100	100–110	110–120	120–130	130–140	140–150	150–160
0–10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10–20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
20–30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
30–40	0	0	0	0	1	9	2	0	0	0	0	0	1	1	0	0
40–50	0	0	0	0	0	5	0	5	2	0	1	0	2	3	0	0
50–60	0	0	0	0	0	2	2	8	3	2	3	4	5	2	3	0
60–70	0	0	0	0	0	3	4	6	6	6	5	6	5	8	5	0
70–80	0	0	0	0	0	4	12	9	11	6	5	8	8	7	1	0
80–90	0	0	0	0	0	1	19	10	7	4	6	6	4	6	2	0
90–100	0	0	0	0	0	3	12	8	8	10	3	3	2	3	0	0
100–110	0	0	0	0	0	0	10	4	5	17	3	8	7	2	1	0
110–120	0	0	0	0	0	0	0	0	0	5	4	2	2	1	2	2
120–130	0	0	0	0	0	0	0	0	0	0	4	1	0	0	0	0
130–140	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
140–150	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
150–160	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
160–170	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
170–180	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0–10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10–20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
20–30	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
30–40	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
40–50	0	0	0	0	2	0	4	1	1	1	1	1	1	0	0	0
50–60	0	0	0	0	0	2	3	4	2	2	2	4	1	0	0	0
60–70	0	0	0	0	0	1	4	10	15	9	3	3	3	0	0	0
70–80	0	0	0	0	0	0	4	11	69	39	15	17	7	1	0	0
80–90	0	0	0	0	0	1	3	21	48	21	30	32	6	1	0	0
90–100	0	0	0	0	0	0	2	6	14	11	23	6	0	0	0	0
100–110	0	0	0	0	0	0	0	0	4	5	1	3	0	0	0	0
110–120	0	0	0	0	0	0	0	0	0	1	3	0	0	0	0	0
120–130	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
130–140	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
140–150	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
150–160	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
160–170	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
170–180	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0–10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10–20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
20–30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
30–40	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
40–50	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
50–60	0	0	0	0	0	0	0	1	0	0	0	0	1	0	0	0
60–70	0	0	0	0	0	0	0	6	6	5	17	3	2	0	0	0
70–80	0	0	0	0	0	0	0	2	101	51	47	7	0	0	0	0
80–90	0	0	0	0	0	0	0	7	55	67	60	14	1	0	0	0
90–100	0	0	0	0	0	0	0	0	21	26	13	0	2	0	0	0
100–110	0	0	0	0	0	0	0	0	1	1	2	0	0	0	0	0
110–120	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
120–130	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
130–140	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
140–150	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
150–160	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
160–170	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 2 Normal Lines and Obtained Strains

Cusp angle	Normal lines		Strain data (μ strain)	
	Mesiodistal	Buccolingual	Mesiodistal	Buccolingual
130 deg	–26	341	23	173.5
140 deg	318	668	55	110.6
150 deg	313	447	59.5	84

Pearson correlation analysis between the normal lines and strain values revealed significance in both the mesiodistal (–0.895) and buccolingual (0.952) directions ($P < .01$).

Discussion

Although the location and magnitude of occlusal forces can be identified using conventional articulating papers or sensing systems,[3–5] the exact 3-dimensional direction of the occlusal forces exerted on a given clinical occlusal surface cannot be determined. Since the normal line distribution showed a close correlation with the resultant strain, it was possible to estimate the force direction on a given occlusal surface by analyzing the normal line distributions. Using a 3-dimensional laser scanning system and software to identify the normal lines for a certain occlusal area, one can estimate the direction of the occlusal forces exerted on that area along with the data obtained using conventional force registration methods.

Conclusion

Within the limitations of the study design, it is suggested that the normal lines of an occlusal surface can be used to estimate the force direction exerted on an implant superstructure.

References

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Literature Abstract

Maxillary sinus augmentation as a risk factor for implant failure

This study aimed to determine whether maxillary sinus augmentation (MSA) was an independent risk factor for implant failure. Seven hundred sixty-two Bicon implants were placed in the posterior maxilla of 318 patients between 1992 and 2000. MSA (including internal-modified Summers and external-modified Caldwell-Luc grafting procedures) was preformed if there was insufficient alveolar bone height to achieve primary implant stability. Additional variables included demographic, health status, anatomy, and implant-specific, abutment-specific, prosthesis-specific, perioperative, MSA-specific, and survival variables. The mean duration of follow-up was 22.5 months (range: 1 to 90.9 months). The results showed statistically significant differences between MSA and non-MSA populations with the following variables: implant location, bone quality, implant coating, well size, implant staging, immediate implant placement, and abutment angle. The 1-year survival rate for implants placed in the posterior maxilla were 96.2% and 92.6% for MSA and non-MSA patients, respectively. The 5-year survival rates for implants placed in the posterior maxilla were 87.9% and 88.0% for MSA and non-MSA patients, respectively. The results of the multivariate model showed that MSA status was not identified as a risk factor for implant failure (adjusted hazard ratio = 1.1, $P = .90$, 95% CI = 0.6 to 1.9). There were 3 risk factors of implant failure, including tobacco use, 1-stage implants, and molar site placement. The risk of implant failure was 3.5 times more likely in smokers compared to nonsmokers (adjusted hazard ratio = 3.5, $P < .001$, 95% CI = 1.7 to 7.2). Implants replacing premolars are 60% less likely to fail compared to implants replacing molars (adjusted hazard ratio = 0.4, $P < .001$, 95% CI = 0.2 to 0.6). Two-stage implants were 90% less likely to fail than 1-stage implants (adjusted hazard ratio = 0.1, $P < .001$, 95% CI = 0.07 to 0.30). The unexpected result was that bone quality was not identified as a risk factor for implant failure. The author concluded that MSA status was not associated with an increased risk for implant failure. Of the 3 factors associated with an increased risk for failure, tobacco use and implant staging may be modified by the clinician to enhance outcomes.

McDermott ME, Chuang SK, Woo VV, Dodson TB. *Int J Oral Maxillofac Implants* 2006;21:366–374. **References:** 71. **Reprints:** Dr Nancy McDermott, Massachusetts General Hospital, Department of Oral and Maxillofaical Surgery, 55 Fruit Street-Warren 1201, Boston, MA 02114. Fax: +617 726 2814. E-mail: nemcdermott@partners.org—*Huong Nguyen, Singapore*