Peri-Implant Bone Loss as a Function of Tooth-Implant Distance

Monika Baron, MD, DMD[a]/Robert Haas, MD, DMD[b]/Werner Baron, DSci[c]/
Georg Mailath-Pokorny, MD, DMD[b]

Purpose: In a retrospective study, the radiographs of 39 patients with Applegate-Kennedy Class I or II in the posterior mandible who had been treated with screw-anchored fixed partial dentures supported by IMZ implants and natural teeth were examined for the presence of radiologically detectable peri-implant bone loss. Furthermore, the results were correlated with a mathematical model. ***Materials and Methods:*** The radiographs of the implants were digitized, and the areas of bone atrophy mesial and distal to the implants were determined semi-automatically. The data obtained were correlated with the distance between the implant and the abutment tooth. The connection between the tooth-supported crown and the implant-supported denture was made with a vertical screw-lock precision attachment. In a mathematical analysis it was assumed that the fixed partial prosthesis was a rigid beam with 3 elastically embedded supports. ***Results:*** The mean distance between the tooth and the first implant was 11.02 mm (SD: 4.24), and between the tooth and the second implant was 20.25 mm (SD: 5.16). Peri-implant bone loss significantly followed a rational function (mesial implant: $P = .03$, distal implant: $P = .02$), meaning that, as the tooth-implant distance increased, the area of atrophy became rapidly larger and then diminished gradually. Distances of 8 to 14 mm between the tooth and the first implant and of 17 to 21 mm between the tooth and the second implant were associated with a more pronounced bone loss. These results were also confirmed mathematically. ***Conclusion:*** A tooth-implant distance of 8 to 14 mm for the first implant and 17 to 21 mm for the second implant should be avoided for implant placement if prosthetic rehabilitation is planned using a fixed partial denture supported by a premolar and 2 IMZ implants in the mandible. Although this investigation was done on IMZ implants only, the results were confirmed by a mathematical model, which indicated that the observed bone loss may be the same in other types of implants placed in the same positions. *Int J Prosthodont 2005; 18:427–433.*

Pathologic changes in the tissues surrounding implants are generally referred to as peri-implant disease. Inflammation of the peri-implant mucosa after osseointegration with simultaneous progressive marginal bone loss is called peri-implantitis[1] and usually gives rise to a crater-like bone loss around the implant. Two main factors are thought to be responsible for the occurrence of peri-implantitis: bacterial infection (plaque theory)[2,3] and mechanical overload (loading theory).[4–6]

Bacterial peri-implantitis has been extensively studied in experimental animals.[7–9] Studies of peri-implantitis caused by mechanical overload are comparatively scarce, and the reported results vary widely.[4,5,10,11] To what extent the severity, duration, and type of mechanical overload are responsible for peri-implant bone loss is still poorly understood. What little is known about the potential negative effects of mechanical overload on peri-implant hard tissue has mainly been derived from finite element analyses and mechanical

[a]*Department of Oral Surgery, Dental School, University of Vienna, Austria; and Ludwig Boltzmann Institute for Oral Implantology, Vienna, Austria.*
[b]*Associate Professor, Department of Oral Surgery, Dental School, University of Vienna, Austria; and Ludwig Boltzmann Institute for Oral Implantology, Vienna, Austria.*
[c]*Engineer, Doctor of Science, Vienna, Austria.*

Correspondence to: *Dr Monika Baron, Dental School of the University of Vienna, Department of Oral Surgery, Waehringerstrasse 25a, A-1090 Vienna, Austria. Fax: +43-1-4277-67019. E-mail: monika.gottschalk-baron@meduniwien.ac.at*

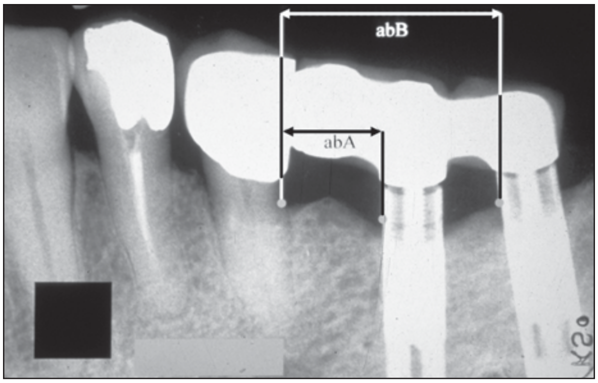

Fig 1 Radiograph of a tooth/implant-supported FPD for measuring tooth–implant 1 (abA) and tooth–implant 2 (abB) distances. The black box in the lower left corner served as a reference square for calculating the amount of peri-implant bone loss.

studies.[12] Several mechanical factors underlying exaggerated bone loss have been addressed. These include the span of the fixed partial denture (FPD), implant shape, implant diameter, implant material, the position and arrangement of the implants, and the fit of the suprastructure.[13–15] Excessive loading is thought to cause microfractures at the coronal bone–implant interface, with resultant marginal bone loss and consequent downgrowth of the epithelium. To ensure optimal long-term implant success, the early detection and elimination of mechanical overload are therefore essential.

Theoretical calculations designed to simulate the interforaminal region of the mandible[16] showed that an increase in the span of an FPD and the cantilever length of a suprastructrure intensifies the load on the most distal implants.[17] To date, however, these calculations have not been confirmed by clinical studies. The management of posterior tooth loss in the mandible compatible with Applegate-Kennedy Class I or II with a FPD supported by 2 implants, and the next mesial natural tooth and anchored with a screw-lock precision attachment is a standard method in implant dentistry. Unlike FPDs supported by implants only, FPDs supported by implants and natural teeth are composed of 2 units with different mechanical properties: the elastically anchored natural tooth and the comparatively rigidly fixed implant. Unfavorable effects of this configuration on the peri-implant hard tissue and the chances of implant survival have not been reported to date. Clinical comparisons of tooth-supported, implant-supported, and tooth/implant-supported FPDs have shown comparable results.[18,19]

IMZ implants (Friatec) feature an intramobile element (IME), which is believed to ensure that their mobility matches that of natural teeth and to dampen the introduction of forces. However, some authors hold that the IME cannot neutralize differential movements of natural teeth and implants,[20] and that there is consequently no need for it.[19]

The loads acting on FPDs supported by both teeth and implants can be computed with the methods used in mechanical engineering (statics, strength testing, dynamics) and with finite element models. These computations show that the span of an FPD and the stresses generated are linearly related (ie, stresses rise as the span of an FPD lengthens).[17]

The purpose of this study was to retrospectively evaluate the effects of the span of tooth/implant-supported FPDs on peri-implant bone loss and relate the findings to a mathematical model.

Materials and Methods

This retrospective study was done in patients with distal mandibular tooth loss (Applegate-Kennedy Class I or II) who received IMZ implants (Friatec).

For admission to the study, the criteria below were defined:

1. The implants had to have been in situ for at least 1 year, with loading for at least 6 months.
2. The implant-supported FPD had to be connected to the first or second premolar by a screw-type attachment (Friatec).
3. The implants had to be at least 11 mm long and 4 mm wide, because shorter implants have been shown to have a significantly poorer chance of survival.[21]
4. The FPD had to be opposed by natural antagonists.
5. Occlusal contacts had to be confined to centric occlusion without eccentric contacts.
6. Inflammatory reactions had to be absent during the entire implant treatment.
7. Oral hygiene had to be flawless (maximum oral hygiene index of 1).[22]
8. The patients had to be enrolled in a standardized recall program.

With a digital slide gauge, the following distances were measured at the coronal implant border on intraoral radiographs:

- Distance between the most distal tooth and the first implant (abA)
- Distance between the most distal tooth and the second implant (abB)

These distances were measured between the distal border of the tooth and the mesial border of the implants (Fig 1). The magnification of the radiographs was determined from the known implant width. The absolute distances measured were divided by the magnification factor.

To measure the areas of atrophy mesial and distal to the implants, the radiographs were digitized. For this purpose they were scanned in together with a reference square (with 5-mm sides) using an A3 flatbed scanner (Sharp JX 600). The reference square was used for computing areas. The extent of bone loss mesial and distal to the implant was manually outlined by the examiner, and the corresponding area was then calculated automatically. For calculating areas, the magnification factor was squared.

The mechanical model of a rigid beam and 3 supports was computed with an equivalent mathematical model, and the presence of a rational relationship between the tooth-implant distance and bone loss was evaluated with computer software for symbolic calculation (Mathcad 8, Mathsoft).

Statistical Analysis

Tooth-implant distances were broken down into 2-mm intervals. For these, mean values and standard deviations of bone loss were computed.

The effects on mesial and distal bone loss were evaluated by a multivariate analysis of covariance that included the variables gender, tooth-implant distance, interimplant distance, and patient age. Furthermore, the relationship between service time of implants and bone loss was evaluated statistically. P values less than .05 were considered statistically significant.

Results

Thirty-nine patients (17 women, 22 men) met the inclusion criteria and were eligible for the study. They were aged between 31 and 87 years (mean age 53.6 years). Their implants had been in situ for 13 to 103 months (mean retention time, 40.8 months and mean loading time 37.8 months).

The mean distance between the natural abutment tooth and the first implant was 11.02 mm (SD: 4.24), and that between the natural abutment tooth and the second implant was 20.25 mm (SD: 5.16). The mean interimplant distance was 5.42 mm (SD: 2.74).

Around the first implant, the mean atrophic area was 6.61 mm^2 mesially (min: 0; max: 23.25; SD: 6.04) and 4 mm^2 distally (min: 0; max: 19.0; SD: 3.45). Around the second implant the mean area of bone loss was 3.32 mm^2 mesially (min: 0; max: 15.3; SD: 3.08) mesially and 3.54 mm^2 distally (min: 0; max: 14.46; SD: 3.50) (Table 1).

The areas of bone loss mesial and distal to the implants were correlated with the distance between the tooth and the first implant. The relationship between peri-implant bone loss and tooth-implant distance was a statistically significant rational function (mesial implant: $P = .03$, distal implant: $P = .02$): As the span of the FPD increased, the areas of bone loss mesial and distal to the 2 implants initially increased rapidly and decreased gradually after reaching a peak, despite increasing tooth-implant distance.

The distance between the tooth and the first or second implants was found to be associated with areas of extensive bone loss. These were 8 to 14 mm (peak 11 mm) for the distance between the tooth and the first implant (abA), and 17 to 21 mm (peak 19 mm) for the distance between the tooth and the second implant (abB) (Table 2).

Patient gender and age did not have any significant effect on peri-implant bone loss ($P = .08$ and $P = .17$, respectively). Additionally, service time of the implants had no influence on peri-implant bone loss ($P = .8$ [first implant], $P = .5$ [second implant]).

Mathematical Model

For the mathematical analysis, the model was construed as a rigid body, ie, a beam with 3 supports, that was elastically embedded in bone (Fig 2).

The model assumed that the 2 implants were at the distances abA and abB away from the tooth. It was assumed further that the horizontal beam was exposed to a vertical bite force (*FK*) at a distance (*DFK*) from the tooth and to a horizontal grinding force (*FM*).

The force *FK* could also be seen as the sum total of a line load, which may be irregularly distributed with its center at the distance *DFK* from the tooth. The forces acting on it displaced the rigid body downward by the amount ν and toward the left by the amount μ and tilted it by an angle α.

To determine ν, μ, and α, the equilibrium conditions were defined as:

- Sum total of horizontal forces = 0
- Sum total of vertical forces = 0
- Sum total of moments around any point = 0

The point of emergence of the tooth from the bone was chosen as the reference point.

The counterforces, which originated in the bone and acted on the parts embedded in bone, were proportional to the displacements, ie, spring constant c for single forces or bedding constant c/L for line forces.

The supports embedded in the jaw sustained a horizontal displacement $y(x) = \mu - \tan(\alpha) \times x$. Because α would definitely be much smaller than 5 degrees, $\tan(\alpha)$ was replaced by α (by radian measurement). Hence $y(x) = \mu - \alpha \times x$, where μ was displacement of the tooth or the implant at the point of emergence from the jawbone. Because of the assumed elastic anchorage, the forces attacking at this point were proportional

Table 1 Tooth-Implant Distance (in mm) and Area of Peri-implant Atrophy in Patients with FPDs Supported by 2 Implants and a Premolar Tooth

			Implant 1			Implant 2				
Patient	Gender	Age (y)	abA (mm)	ma (mm^2)	da (mm^2)	abB (mm)	mb (mm^2)	db (mm^2)	abC (mm)	Time in situ (mo)
A.N.	F	44	7.22	4.24	1.44	12.87	2.88	2.00	1.99	56
A.O.	F	41	6.50	5.07	2.13	19.46	7.30	5.07	7.40	24
A.R.	F	52	6.08	4.62	2.16	12.25	1.60	3.09	1.84	14
E.B.	M	66	6.35	2.93	1.25	15.79	2.05	2.30	6.19	52
E.H.	M	65	12.81	3.15	2.20	19.38	0.63	1.68	4.02	100
E.K.	M	44	11.92	9.67	5.00	18.27	6.25	0.98	3.44	28
E.K.	M	46	9.95	6.35	3.56	23.88	2.43	1.40	11.20	41
E.L.	M	66	7.30	1.85	1.60	15.54	0.00	0.00	4.51	36
E.N.	M	46	6.27	2.70	1.48	15.49	2.45	2.78	6.58	47
E.R.	F	61	12.60	23.25	3.40	20.45	3.00	3.70	2.04	20
E.S.	F	65	11.80	4.70	3.00	21.80	3.24	2.24	7.31	36
E.T.	F	61	9.60	7.67	1.50	16.10	0.00	0.00	2.60	19
F.A.	F	61	9.42	20.56	4.34	18.40	3.90	13.14	2.30	13
G.H.	F	31	12.18	8.33	5.30	20.67	4.15	2.75	5.33	58
G.H.	F	73	11.41	25.00	19.00	19.78	9.50	9.75	6.37	55
H.E.	F	47	10.90	2.03	3.00	20.15	2.50	3.33	5.50	37
H.H.	M	45	9.65	1.95	1.12	22.02	1.23	1.38	3.62	31
H.K.	M	45	14.46	0.79	0.76	22.64	0.55	0.80	4.28	19
H.K.	F	60	6.68	3.45	2.25	13.35	3.00	1.90	2.56	69
H.M.	M	38	10.56	7.12	5.00	30.90	7.44	1.59	16.20	41
H.P.	F	78	8.40	18.20	10.60	20.67	8.10	8.40	7.90	95
H.T.	F	70	4.99	2.99	2.23	13.79	2.99	2.83	5.87	39
H.U.	M	45	12.37	8.06	5.70	19.40	4.73	6.52	4.71	42
I.B.	F	59	19.83	0.00	0.00	27.82	1.99	1.33	4.59	57
J.S.	F	53	4.29	2.49	4.23	15.32	3.75	4.41	6.40	45
J.U.	F	53	4.75	2.25	1.21	13.10	0.70	0.12	4.20	33
K.E.	M	52	18.64	2.25	3.50	29.33	1.88	1.83	5.29	26
K.K.	M	54	17.64	5.10	5.55	28.33	3.76	7.67	7.08	103
M.B.	F	37	10.82	15.90	7.50	18.85	5.75	2.40	4.23	59
M.R.	M	49	13.49	4.16	6.00	20.18	4.00	7.60	3.00	21
P.H.	M	47	12.21	6.75	5.40	18.70	4.50	4.63	3.02	17
R.G.	M	42	20.87	6.35	4.08	30.67	0.88	2.00	5.98	36
R.K.	M	87	4.40	1.14	1.02	11.83	1.02	2.14	2.95	24
R.S.	M	66	12.59	7.56	9.53	23.70	1.50	3.06	7.64	44
R.W.	M	66	14.50	7.63	4.34	24.50	3.90	7.97	6.40	42
V.V.	M	44	16.30	8.10	3.33	27.20	0.00	0.00	7.59	23
W.H.	M	34	12.92	5.60	1.33	21.12	0.00	0.00	4.43	21
W.M.	M	63	12.64	5.90	7.77	20.17	15.30	14.46	7.78	24
W.S.	M	36	14.49	2.00	2.86	25.77	0.62	0.62	7.10	44

abA = distance tooth–implant 1; ma, da: mesial and distal area of atrophy around implant 1 in mm^2; abB = distance tooth–implant 2; mb, db: mesial and distal area of atrophy around implant 2; abC = distance between implant 1 and 2 in mm.

to it. The solution of the equilibrium conditions gave the dependence of μ upon the parameter of the mechanical model. The dependences on abA and upon abB were of the same form, namely a rational function:

$$f(x) = \frac{a \times x + b}{c \times x^2 + d \times x + e}$$

The curve corresponding to this function was characterized by a steep rise and a steep fall to a flat line (Fig 3). Because it described the force acting on the bone at the point of entry of the implants with increasing span lengths of the FPD, it may well have explained the measured areas of bone loss.

Discussion

This study was designed to shed light on the relationship between tooth-implant distance and peri-implant bone loss by measuring the bone loss around IMZ implants in the posterior mandible on radiographs. No FPDs other than those supported by 2 implants and connected to a premolar with a screw-lock precision attachment were considered for the study. To preclude potential associated factors, the patients enrolled in the study had to be free 0f inflammatory reactions throughout the follow-up time and had to have their implants in situ for a sufficiently long time.

To determine the extent of the crater-like bone loss around the implants, standardized intraoral radio-

Table 2 Mean Values and Standard Deviations of Areas of Atrophy Mesial and Distal to the Implant as a Function of Tooth-Implant Distance

abA (mm)	ma ± SD (mm²)	da ± SD (mm²)	ma + da ± SD (mm²)
Implant 1			
4–6	2.22 ± 0.78	2.17 ± 1.47	2.20 ± 1.09
6–8	3.55 ± 1.15	1.76 ± 0.41	2.66 ± 1.25
8–10	10.95 ± 8.03	4.22 ± 3.81	7.59 ± 6.90
10–12	10.74 ± 8.44	7.08 ± 6.07	8.91 ± 7.27
12–14	8.08 ± 5.95	5.05 ± 2.61	6.57 ± 4.72
> 14	4.03 ± 3.16	3.05 ± 1.85	3.54 ± 2.55
Implant 2			
11–13	1.83 ± 0.93	2.41 ± 0.59	2.12 ± 0.78
13–15	2.23 ± 1.33	1.62 ± 1.38	1.92 ± 1.25
15–17	1.65 ± 1.63	1.90 ± 1.90	1.77 ± 1.68
17–19	5.10 ± 1.09	5.29 ± 5.45	5.19 ± 3.64
19–21	5.92 ± 4.27	6.33 ± 3.88	6.12 ± 3.98
21–23	1.26 ± 1.42	1.11 ± 0.94	1.18 ± 1.12
> 23	2.44 ± 2.16	2.75 ± 2.79	2.59 ± 2.44

abA = tooth–implant 1; ma, da = mesial and distal areas of atrophy around implant 1; abB = tooth–implant 2; mb, db = mesial and distal areas of atrophy around implant 2; SD = standard deviation.

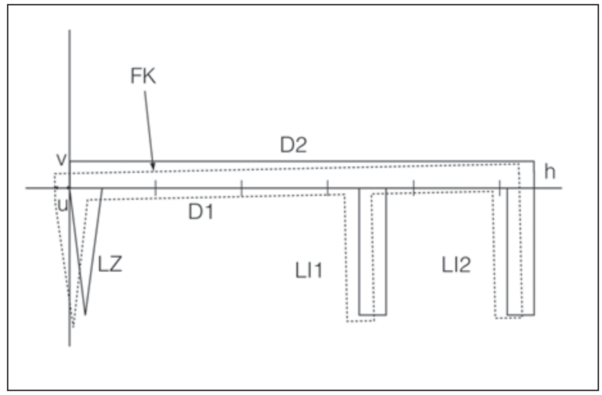

Fig 2 Drawing of an FPD supported by 1 natural tooth and 2 implants, either with *(dotted line)* or without *(continuous line)* loading. For further details, see text.

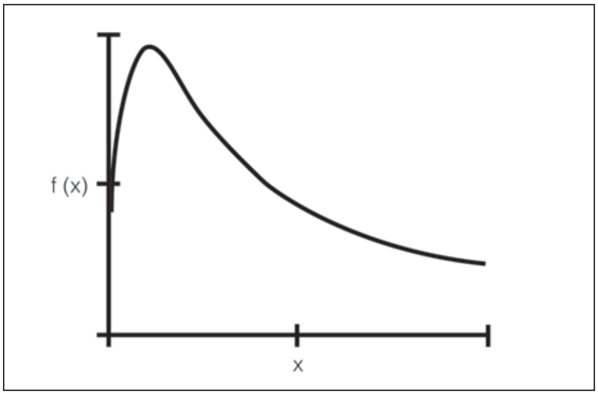

Fig 3 Peri-implant stress (f(x)) as a function of tooth-implant distance (x) evaluated mathematically.

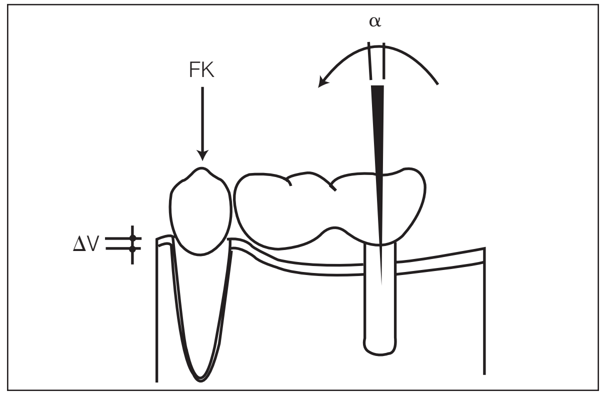

Fig 4 Drawing of tooth/implant-supported FPD exposed to a defined vertical load (for details, see text).

graphs were digitized and stored as images, so that the areas of bone loss were highlighted as white patches contrasting with the surrounding bone. Since radiographs are mainly shaded in different intensities of gray, contours cannot be detected automatically by the computer and thus had to be corrected manually by a trained person.

Although it is known that the majority of bone loss occurs during the first year of loading,[23] no influence of implant service time on bone loss was proven in the present study.

Whereas patient age and gender had no significant influence on the present results, this study of tooth/implant-supported FPDs in the posterior mandible showed that at a certain tooth- implant distance, the amount of bone loss is clearly increased. For FPDs supported by 1 tooth and 2 implants, this distance was 8 to 14 mm from the mesial implant and 17 to 21 mm from the distal implant, with peak distances of 11 and 19 mm, respectively.

Instead of the expected linear relationship, the areas of bone loss in this study followed a rational function. This meant that, with increasing tooth-implant distances, the area of bone loss initially increased but then decreased after a peak was reached.

Mechanically, the introduction of a force into the system involves a complex interaction of forces, counterforces, tooth intrusion/implant tilting, moments, and varying stresses in the peri-implant bone. Figure 4 illustrates the possible mechanical interaction underlying the observed results. If a tooth is exposed to a force FK, it is intruded by an amount ΔV by virtue of its desmodontal suspension, while the implant is tilted by an angle α. With short spans of the FPD, the intrusion of the tooth is limited by the comparatively rigid implant. The implant reaches a maximum tilt angle α. Implant tilting is both contained and determined by the elasticity of the host bone. As the span of the FPD increases, the tooth is progressively intruded, but its intrusion is still limited by the maximum tilt angle of the implant, which is dictated by the host bone. The maximum implant tilt angle remains unchanged until the span of the FPD becomes long enough to permit maximum tooth intrusion. As the lever arm increases, the moment acting on the implant becomes progressively more powerful and causes the stresses in the peri-implant bone to rise. This moment continues to rise until the tooth is maximally intruded with increasing span length of the FPD. Once the tooth is maximally intruded, the moment does not rise any more, even when the cantilever is further extended. But the tilt angle α becomes progressively smaller with increasing cantilever lengths once the tooth is maximally intruded.

The results of this study suggest that the 2 variables described, ie, tilt angle and moment, while interacting biomechanically, develop differential effects depending on the tooth-implant distance. As the span of the FPD is increased, the moment initially becomes larger, while the tilt angle remains the same, until the tooth is maximally intruded. As a consequence, the area of peri-implant bone loss increases. Once the tooth is maximally intruded, the moment remains constant, while the tilt angle decreases. As a consequence, the area of peri-implant bone loss decreases.

The present clinical study has proven the influence of the tooth-implant distance on bone loss for IMZ implants, which contain a special IME. Whether the observed correlation of tooth-implant distance and bone loss in the present study is valid in other implant systems has to be shown in further investigations. It seems most likely that when looking at other implant systems the results may be the same for 2 reasons:

1. The function of the IME of IMZ implants seems similar to that of other abutment connections.[24]
2. The mathematical model was created and the calculations performed independently of the implant system.

The quality and elasticity of the peri-implant bone, which are apparently responsible for the extent of implant tilting and probably also for the extent of bone loss, were beyond the scope of this study and were therefore ignored. Also, the periodontal ligament, which might play a role in stress distribution between the tooth and implant, was not taken into consideration.[25]

There may yet be other factors affecting peri-implant bone loss. These cannot be ruled out altogether and should be evaluated by prospective comparative studies. But because the mean area of bone loss in absolute terms was largest at the site of the maximal biomechanical stress in this study, peri-implant bone loss is likely to be mainly a result of mechanical overload. This is supported by the absence of peri-implantitis and the compliance with optimal oral hygiene in all of the patients examined.

Conclusions

In this retrospective clinical study and the computed mathematical model, it was shown that a distance of 8 to 14 mm (for the mesial implant) and 17 to 21 mm (for the distal implant) resulted in statistically significant peri-implant bone loss. The placement of IMZ implants at this specific distance should therefore be avoided when restoration of the posterior mandible is performed with a tooth/implant-supported FPD. Whether this is true of other implant systems remains to be proven in further investigations.

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Literature Abstract

The effect of fiber reinforcement on the fracture toughness and flexural strength of provisional restorative resins

The purpose of this study was to compare the effects of 6 different types of fibers on the fracture toughness and flexural strength of polymethyl methacrylate (PMMA), polyethyl methacrylate (PEMA), and bis-acrylic resins. A total of 105 specimens were prepared for the fracture toughness test and flexural strength test. The specimens were divided into 3 groups according to the type of resin used: Jet, Trim, or Temphase (n = 35), and then into 7 subgroups (n = 5) according to the type of fiber reinforcement: Construct, Fibrestick, Ribbond normal, Ribbond THM, Ribbond triaxial, or Fibrenet. Unreinforced specimens were used as the control. Specimens were loaded into a universal testing machine until fracture. The mean fracture toughness ($MPa^{1/2}$) and mean flexural strength (MPa) were compared by 1-way analysis of variance, followed by the Tukey standardized range test (α = .05). The following results were found: *(1)* The use of fibers is an effective method to increase the fracture toughness and flexural strength of provisional restoration resin; *(2)* The surface treatment of the fibers greatly influences their effect on the fracture toughness and flexural strength of provisional restoration resin.

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Reprints: Dr Stephen F. Rosenstiel, Professor and Chairman, Restorative and Prosthetic Dentistry, Ohio State University College of Dentistry, 305 W 12th Avenue, PO Box 182357, Columbus, OH 43218-2357.
E-mail: rosensteil.1l@osu.edu—*Khaldoun Alajlouni, UNMC College of Dentistry, Lincoln, NE*