The Use of Tilted Implant for Posterior Atrophic Maxilla

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ABSTRACT

Purpose: To retrospectively analyze the influence of implant inclination on marginal bone loss at freestanding implant-supported fixed partial prostheses (FPPs) over a medium-term period of functional loading.

Materials and Methods: Twenty-nine partially edentulous patients with freestanding FPDs supported by two implants placed in a two-stage procedure comprised the study group. The anterior implant was placed axially, and the posterior tilted distally. Mesial or distal inclination of each implant was measured in relation to the vertical axis perpendicular to the occlusal plane. Average bone loss was compared between straight and tilted implants, smokers, and nonsmokers.

Results: Mean angulation of the anterior axial-positioned implant was 3.45 degrees distally (range 0–8) and of the distal implants was 32.83 degrees distally (range 20–50 degrees). Average bone loss after 1, 3, and 5 years was 0.89 (SD = 0.73), 1.18 (SD = 0.74), and 1.50 (SD = 0.81), respectively, for axial implants, and 0.98 (SD = 0.69), 1.10 (SD = 0.60) and 1.50 (SD = 0.67) for tilted implants, with no significant correlation between implant angulation and bone loss. A significant correlation between implant angulation and annual bone loss was obtained for tilted implants only ($r = 0.52$, $p = .004$).Using Albrektsson criteria, the success rate was 89.6% (26 out of 29 implants) for straight and 93.1% (27 out of 29) for tilted implants.

Conclusion: The study demonstrates no effect of implant angulation on peri-implant bone loss in the posterior maxilla.

KEY WORDS: bone loss, tilted implants

INTRODUCTION

Dental implants have tremendously changed treatment planning for partially edentulous patients. However, a critical determinant for successful implant placement is sufficient height and width of the residual ridge of bone. Ideally, implants should be placed parallel to the other one and to adjacent teeth and be aligned vertically with axial forces. Rehabilitation of edentulous posterior maxilla with endosseous implants is often associated with anatomic limitations, mainly loss of the alveolar bone and pneumatization of the maxillary sinus.[1] Although grafting the maxillary sinus is a common surgical intervention aimed to augment bone height prior to or simultaneous with the placement of endosseous dental implants, this procedure has disadvantages such as increased morbidity, possible surgical complications, high cost, and a longer healing period of time.[2] Alternative treatment options for fixed restorations of the atrophic posterior maxilla without bone grafting include implant-supported fixed partial denture with a distal cantilever, use of short implants, and implant placement in the zygoma or the tuberosity.[3,4] Another option is the placement of a distally tilted posterior implant immediately anterior to the maxillary sinus.[4]

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The main advantage of tilted implant design (TID) is the extension of the fixed implant-connected prostheses further distally, thus reducing the length of cantilever without the need for sinus floor elevation procedure.[4] Using this technique, the posterior implant is usually tilted along, anterior, and parallel to the anterior border of the maxillary sinus, while the anterior implant is placed perpendicular to the occlusal plane.[4] The use of TID may provide several clinical advantages: (1) It enables the placement of longer implants, thus increasing bone-to-implant contact area and implant stability; (2) it creates a wider distance between the anterior implant and the posterior one resulting in improved load distribution; and (3) it significantly reduces the distal cantilever size or completely eliminates it. These advantages simplify the surgical procedure and reduce morbidity, time, and cost, thus availing treatment to a greater number of patients.[4]

The TID requires the use of angled abutments. Several studies have suggested that angled abutments result an increased stress on the supporting implants and the adjacent bone.[5–10] This strain has been claimed to increase with decreasing osseous density.[7] It appears that despite a 3.0- and 4.4-fold stress increase on 15° and 25° angled abutments respectively, the stress on bone usually remain within physiological limits, compared with straight abutments.[7] In spite of the ample in vitro data that exist regarding stress distribution using different implant angulations, bone density, and loading forces,[6,8,9,11] it is difficult to extrapolate this information to humans.

Several articles addressed the survival rate of implants and prostheses involving the use of angled abutments.[12–15] Most of the studies dealt with full arch restorations with but a few including partial arch cases.[4,13–18] All of these studies reported high implant survival rate, and three studies reported radiographic data[15,16,18] and a few related to prosthetic complications.[13–15] Therefore, the purpose of present study was to analyze the long-term effect of the inclination of functionally loaded implants on the marginal bone loss, based on clinical and radiographic findings. Prosthetic complications were also recorded.

MATERIALS AND METHODS

Case Selection

The study consisted of 29 consecutively treated patients who met the inclusion criteria requiring restoration of the posterior maxilla. Patients were treated during the years 1996 to 2013 by the senior author (E.B.). Patients were selected from a group that was initially considered as candidates for posterior upper implant placement and sinus augmentation procedures. The opposing mandibular occlusal surfaces were natural teeth in 21 (72.4%) patients or implant-supported fixed restorations in eight (27.6%). Each subject signed an informed consent form regarding implant treatment, and a detailed explanation regarding the treatment and other optional treatments was given.

The study was approved by the ethics committee of Tel-Aviv University.

Exclusion criteria were as follows: uncontrolled diabetes, immune diseases, radiation therapy to the head and neck region, chemotherapy during 12 months before proposed implant placement, untreated pathologies in the anterior teeth, uncontrolled periodontal disease, and psychological problems. Seventeen patients who presented limited bone volume requiring height and/or width augmentation to allow the placement of two implants in the posterior maxilla were excluded in those a one- or two-stage lateral sinus elevation procedure was performed.

Twenty-nine patients met the inclusion criteria. Ages varied between 40 and 83 years (Table 1). Each patient received two dental implants: The posterior one was installed along the anterior sinus wall at angles ranging between 20 and 50 degrees in relation to the occlusal plane and one implant anterior to it that was placed perpendicular to the occlusal plane (0–8 degree of angulation). The tilted implant required for appropriate fabrication of an implant restoration. Fifty-eight (58) threaded, self-tapping dental implants (Biocom-MIS Implant technologies, Bar Lev Industrial Park, Israel) were placed in these patients; 29 implants were restored with preangled or custom-angled abutment, and 29 were restored with standard abutments (Table 1). Implant evaluation was conducted at the time of prosthesis placement and at the time of data collection.

Treatment Protocol

A thorough presurgical evaluation including full mouth periodontal chart, occlusal analysis, study of the mounted casts, and diagnostic wax up was performed. Initial periodontal therapy including oral hygiene instructions and training, scaling, and root planning wherever indicated was carried out. Patients were

TABLE 1 Data of Implants with Regard to Position, Length, Diameter, and Angle to Occlusal Plane

Patient	Gender	Age (At Implant)	Implant Site	Implant Length	Implant Diameter	Bridge Units	Cantilever	Angle to Occlusal Plane	Bruxer
1	M	71	25	11.5	3.75	2	0	5	Yes
			26	16	3.75		0	31	
2	F	71	24	13	3.75	3	0	4	No
			26	16	3.75		0	30	
3	M	70	13	13	3.75	4	0	0	No
			15	16	3.75		1	26	
4	F	56	24	13	4.2	3	0	7	No
			26	16	3.75		0	29	
5	F	77	24	16	3.75	4	0	2	No
			26	16	3.75		1	26	
6	F	56	24	16	3.75	3	0	3	No
			26	16	3.75		0	42	
7	M	74	14	16	3.75	3	0	3	Yes
			17	16	4.2		0	37	
8	M	54	14	13	3.75	3	0	1	No
			16	16	4.2		0	26	
9	M	75	14	16	3.75	3	0	8	No
			16	13	3.75		0	23	
10	M	55	14	13	3.75	3	0	5	No
			16	13	4.2		0	28	
11	M	63	14	11.5	3.75	3	0	1	No
			16	16	3.75		0	34	
12	M	63	24	13	3.75	3	0	2	Yes
			26	13	3.75		0	34	
13	F	63	24	13	3.75	3	1	4	Yes
			26	16	3.75		0	31	
14	F	65	14	13	3.75	3	0	8	Yes
			16	16	4.2		0	28	
15	F	63	14	11.5	4.2	3	0	4	No
			16	16	4.2		0	36	
16	F	73	24	13	3.75	3	0	1	Yes
			26	13	3.75		0	28	
17	F	68	24	11.5	4.2	3	0	5	Yes
			26	16	4.2		0	36	
18	M	60	24	11.5	4.2	3	0	2	Yes
			26	11.5	4.2		0	43	
19	M	59	14	13	3.75	3	0	3	No
			16	16	3.75		0	36	
20	M	77	25	11.5	3.75	2	0	1	Yes
			26	11.5	3.75		0	37	
21	F	48	12	11.5	4.2	4	1	8	No
			15	13	3.75		0	28	
22	F	78	14	13	3.75	3	0	0	No
			16	13	4.2		0	26	
23	F	40	15	11.5	3.75	2	0	2	No
			16	13	3.75		0	25	
24	M	70	24	13	3.75	3	0	5	No
			26	13	3.75		0	40	
25	F	60	24	13	3.75	3	0	2	No
			26	13	3.75		0	49	
26	M	59	14	11.5	3.75	3	0	3	No
			16	16	3.75		0	38	
27	M	65	14	13	3.75	3	0	4	No
			16	13	3.75		0	20	
28	M	55	24	13	3.75	3	0	2	No
			26	13	3.75		0	50	
29	M	83	24	13	3.75	3	0	5	No
			26	13	3.75		0	35	

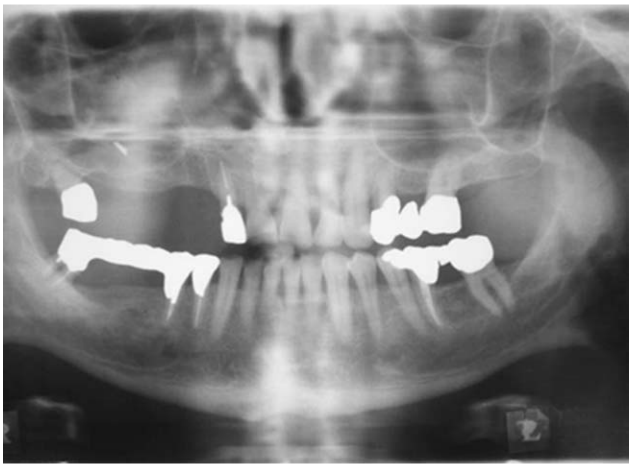

Figure 1 Preoperative panoramic x-ray demonstrating insufficient bone for implant placement in the posterior right maxilla.

reevaluated, and wherever indicated, additional periodontal therapy aimed to reduce periodontal probing depth and bleeding on probing, and improvement of plaque control to achieve hygiene index (HI) below 10% was carried out.[19] All patients presented an initial full mouth periapical radiographs and panoramic radiographs (Figure 1) or CT scans prior to implant placement. Periapical radiographs of the implants were repeated 6 months after implant placement, before implant exposure, and immediately at FPP installation and then at the annual follow-up examinations.

Patients were maintained by a trained oral hygienist every 3 to 6 months. Each visit included a clinical examination and periodontal charting, oral hygiene instructions, and scaling and root planning wherever needed. The implants were considered successful if they fulfilled the criteria set up by Albrektsson and Zarb.[20] One hour before surgery, the patients were premedicated with 875 mg amoxicillin and clavulanic acid (Augmentin, GlaxoSmithKlein, Brentford, UK). Penicillin-sensitive patients were premedicated with clindamycin HCL (Dalacin-C, Pfizer NV/SA, Belgium) 150 mg bid. Patients rinsed with 0.2% chlorhexidine solution (Tarodent, Taro Pharmaceutical Industries, Yakum Business Park, Yakum, Israel) for 1 minute before initiation of the surgical procedure.

Surgical Technique

Full-thickness flaps were raised under local anesthesia, using a mid-crestal incision, and mesial and/or distal releasing incisions when required to improve visual or surgical access. The entrance point of the distal implant was interpreted by measuring the distance from the anterior tooth with a dental caliper[γ] using a CT scan or a panoramic radiograph (Figures 2 and 3, A and B). The osteotomy angle and direction were made after locating the position of the anterior wall of the sinus, using a pilot drill, 2.0 mm in diameter (Figure 3C). At this stage, a periapical x-ray was performed, aimed to check and precisely determine the accuracy of the drilling in order to avoid perforation of the sinus wall.

This was followed by successive drilling according to the planned implant length and width and insertion of the distal tilted implant (Figure 4, A and B). The anterior implant was placed in the available bone between the distal tooth present and the posterior implant, parallel to the tooth and roughly perpendicular to the bone crest, as determined best by the surgeon (Figures 5 and 6). Implants were placed manually in a supracrestal manner (leaving the smooth neck of the implants supracrestally).

Postoperative Management

Following surgery, patients were administered with 875 mg amoxicillin with clavulanic acid (Augmentin) bid. Penicillin-sensitive patients were administered with clindamycin HCL (Dalacin-C) 150 mg bid. Antibiotic therapy was continued during the first week postoperatively. Whenever needed, analgesic drug (Naxyn, naproxen 250 mg, Teva Pharmaceutical Industries, Petah Tikva, Israel) was given twice a day; 0.2% Chlorhexidine mouth rinse (Tarodent) was prescribed

Figure 2 Clinical view of the edentulous posterior right maxilla.

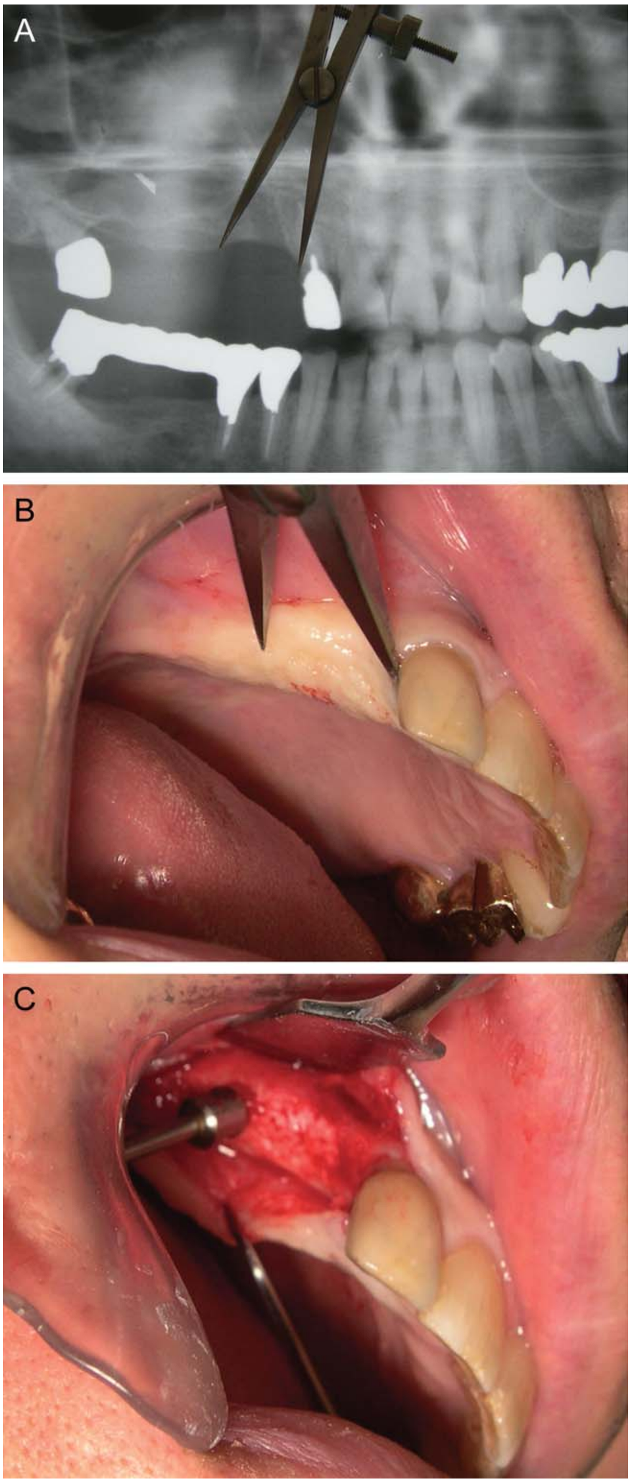

Figure 3 *A*, Planning of the osteotomy entrance of the distal implant. *B*, Transferring the measurements from the panoramic x-ray to the surgical site. *C*, A parallel pin demonstrating the location and angulation of the distal tilted implant.

twice daily for 1 minute over a 3-week period of time. Patients were instructed to avoid the use of a removable prosthetic devises until after the sutures were removed (i.e., 10 to 14 days postoperatively).

Healing Time

Implants were exposed 6 months after placement. Depending on the width of the crestal masticatory mucosa, either a midcrestal or a paracrestal (palatal), incision was made, intending to achieve at least 3 mm of keratinized mucosa on the implants buccal aspect.

Prosthetic Procedures

Three weeks after implants uncovering, impressions were taken using the open tray technique. Impression copings were screwed and connected to each other with an auto polymerizing acrylic resin (pattern resin, GC

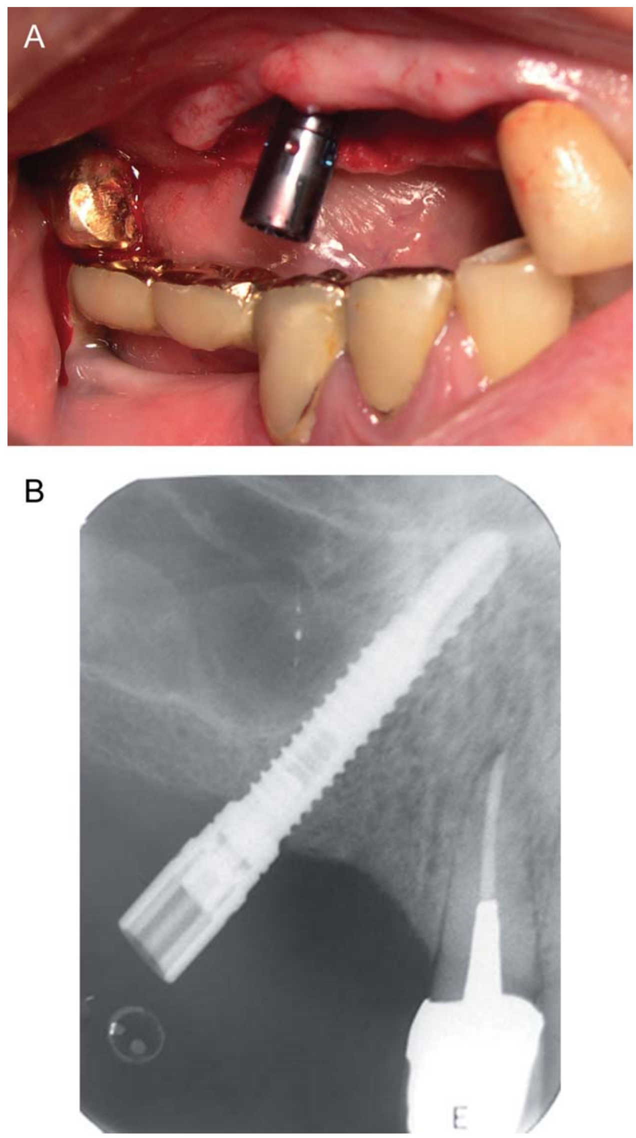

Figure 4 *A*, Clinical view of the distal implant, immediately after placement. *B*, Radiographic verification of the distal implant position and its relationship with the surrounding anatomic landmarks, especially the anterior wall of the sinus.

Figure 5 The mesial implant is placed in the remaining space between the distal implant and the anterior tooth.

Figure 7 Prefabricated abutments connected to implants.

America, Alsip, IL USA). Impressions were taken using putty and silicone wash (Express, 3M ESPE dental products, ST. Paul, MN, USA) in plastic stock trays. A master model was prepared, and interarch relations were recorded. At the following appointment, abutments were connected (Figure 7), and the metal framework was tried.

At this stage, a silicone pick-up impression of the metal framework in situ was taken, and acrylic resin provisional bridges were fitted. The permanent three-unit porcelain fused to metal fixed partial denture was cemented after occlusal adjustment and glazing

Figure 6 Radiographic verification of the relationships between the implants, and the neighboring tooth/sinus.

(Figure 8, A and B), with temporary cement (Temp-Bond Kerr Corporation, West Collins Avenue, CA, USA).

Survival Criteria

Implants were evaluated and classified in a three-field table, according to the criteria suggested by Albrektsson and Zarb[20] in 1998 namely: Success: implant immobility, lack of peri-implant radiolucency, bone loss not exceeding 1.5 mm during the first year of service, and 0.2 annually in the successive years, and absence of persistent and/or irreversible signs and symptoms such as pain, infections, and neuropathies. Survival: implants that were stable but did not meet the bone loss criteria mentioned above. Failure: implants that had to be removed for any reason.

Radiographic Measurements. Postoperative radiographic examinations were performed at FPP installation and at the annual follow-up examinations. Standardized radiographs, with the film kept parallel (Kodak Ektaspeed Plus, Eastman Kodak Co., Rochester NY, USA) and the x-ray beam perpendicular to the implant, were taken using plastic film holders (Dentsply-Rinn Corporation, Elgin, IL, USA).

Bone level associated with the implants was evaluated on parallel periapical x-rays using computerized digital radiography (Schick Technologies, New York, NY, USA) (Figure 9).

Radiographic evaluation was made by measuring the distance between the alveolar bone crest and implant shoulder mesial and distal to the implant. Radiographic

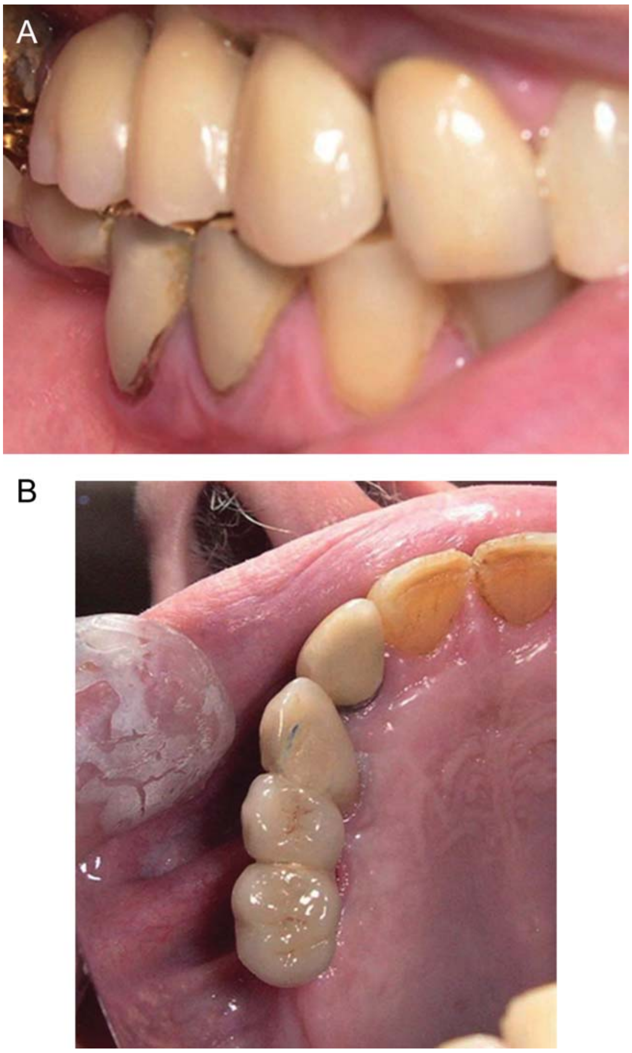

Figure 8 *A*, Clinical view of final rehabilitation. *B*, Narrow occlusal pattern of final porcelain fused to metal (PFM) bridge.

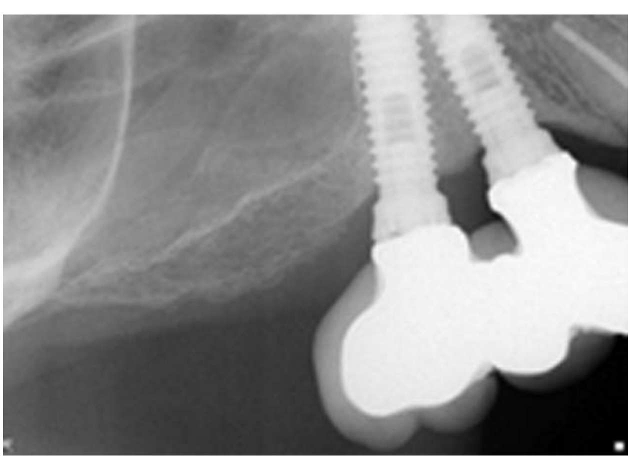

Figure 9 Periapical view 9 years after loading.

distortion was calculated by dividing the radiographic implant width by the actual one. Bone loss (mesial + distal\2) was measured initially at the time of FPPs installation (7–8 months after implant placement) and at 1, 3, 5, and 10 years and once again at the time of data collection (up to 17 years) (Table 2). The difference (D-delta) between final and initial measurements was calculated accordingly.

Implant angulation was measured by tracing lines through the occlusal plane and parallel with the long axis of the implants. Angulation between each implant and the occlusal plane was calculated by reducing the angle of the intersection from 90 degrees (Figure 10).

Prosthodontic Complications. Prosthodontic complications during the study period were recorded.

Statistical Analysis

Statistical analysis was performed with the *SPSS* 20.0 statistical analysis software (SPSS Inc., Chicago, IL, USA). The primary outcome variable in this study was the change in peri-implant marginal bone level from the time of FPD placement to the latest follow-up examination. Comparison between axial and tilted positioned implants was performed by the use of *t*-tests for dependent samples. Descriptive statistics for continuous variables were summarized as the mean value ± standard deviation. *t*-Tests for independent samples were used to compare smokers and nonsmokers as well as women and men; the Pearson correlation coefficient test was used to test for correlation between age, and outcome measures *p* value equal or less than .05 was considered statistically significant.

RESULTS

The files of 29 patients (16 males; 13 females) met the inclusion criteria (Table 1). In these, 58 implants were placed, two at each site. Age ranged between 40 and 83 years (avg = 64.5, SD = 9.8). The relevant individual data of each patient in the study group, including parafunctional habits (bruxism), site, and type of each implant, are shown in Table 1. Implant's diameter varied between 3.75 and 4.2 mm (mean 3.85, SD 0.19) (Table 1).

Twenty-nine pairs of implants were restored; in each pair, there is one with a standard abutment and one with an angled abutment (Table 1). Angulations between axial implants and the occlusal plane varied

TABLE 2 Radiographic Data and Smoking Habits

			Axial							Tilted						
	Smoker	Follow-Up Years	Mean Initial Bone Loss Implant	1-Year Implant	3-Year Implant	5-Year Implant	10-Year Implant	Mean Final Bone Loss Implant	Permitted Bone Loss Albrektsson and colleagues 1998	Mean Initial Bone Loss Implant	1-Year Implant	3-Year Implant	5-Year Implant	10-Year Implant	Mean Final Bone Loss Implant	Permitted Bone Loss Albrektsson and A colleagues 1998
1	No	*17*	1.25	1.25	1.5	1.55	1.8	1.8	4.7	1.15	1.35	1.45	1.35	1.35	1.35	4.7
2	No	*15*	1.40	1.55	1.55	1.6	1.8	1.95	4.3	1.4	1.55	1.45	1.75	1.75	1.75	4.3
3	No	*9*	1.6	1.6	1.65	1.7		1.7	3.1	1.7	1.85	1.95	2		2.05	3.1
4	Yes	*8*	0.55	0.5	0.7	0.8		0.8	2.9	1.65	1.9	2.2	2.35		2.3	2.9
5	No	*7*	0	0.35	0.4	0.4		0.35	2.7	0	0.4	0.7	0.8		0.8	2.7
6	Yes	*7*	1.1	1.35	1.6	1.75		1.8	2.7	1.75	1.9	2	2.1		2.1	2.7
7	Yes	*9*	0.5	0.85	0.85	1		0.95	3.3	0.6	1.35	1.4	1.7		1.7	3.3
8	Yes	*6*	1.6	1.7	1.6	1.6		1.6	2.5	1.15	1.25	1.35	1.35		1.4	2.5
9	No	*3*	0.8	0.8	0.85			0.85	1.9	0	0.1	0.1			0.1	1.9
10	Yes	*5*	0.1	1.1	1.2	1.35		1.35	2.3	0.25	1.2	0.9	0.95		0.95	2.3
11	No	*5*	2.55	3	3.05	3.6		*3.6**	2.3	2.6	2.7	1.7	2.85		*2.85**	2.3
12	Yes	*5*	0.8	1	1.2	1.1		1.1	2.3	0.6	0.7	0.65	0.65		0.65	2.3
13	Yes	*4*	0.65	0.8	1.1			1.1	2.1	0	0.5	0.6			0.65	2.1
14	Yes	*4*	0	0.1	0			0	2.1	0.3	0.3	0.3			0.3	2.1
15	Yes	*5*	2	2.3	2.5	2.5		*2.5**	2.3	0.55	1	0.65	0.75		0.75	2.3
16	No	*4*	0.2	0.65	0.65			0.65	2.1	0.3	0.4	0.5			0.5	2.1
17	No	*1*	0.55	0.6				0.6	1.5	1.1	1.25				1.25	1.5
18	No	*2*	0	0				0	1.7	0.15	0.4				0.4	1.7
19	No	*4*	1.5	1.7	1.7			1.7	2.1	0.55	1.2	1.5			1.65	2.1
20	No	*3*	0	0.05	0			0	1.9	1.4	1.4	1.4			1.4	1.9
21	No	*2*	0	0.35				0.35	1.7	0	0				0	1.7
22	No	*5*	0.15	0.9	0.55	0.55		0.55	2.3	0.85	0.75		0.85		0.85	2.3
23	No	*3*	0.35	0.85	0.95			0.95	1.9	0.3	0.4				0.4	1.9
24	No	*2*	0.25	0.1				0.05	1.7	0.2	0.4				0.5	1.7
25	Yes	*1*	1.6	1.65				*1.65**	1.5	1.9	2.3				*2.3**	1.5
26	No	*1*	0.35	0				0	1.5	0.25	0.3				0.3	1.5
27	No	*2*	0	0.1				0	1.7	0.8	0.95				1.05	1.7
28	No	*1*	0	0				0	1.5	0.45	0.65				0.65	1.5
29	No	*1*	0.4	0.55				0.55	1.5	0	0				0	1.5
Average		*4.86*	0.70	0.89	1.18	1.50	1.80	0.80	2.28	0.76	0.98	1.10	1.50	1.55	1.07	2.28
St. dev		*3.83*	0.71	0.73	0.74	0.81	0.00	0.65	0.79	0.68	0.69	0.60	0.67	0.20	0.64	0.79

*Survival = permitted bone loss of no more than 1 mm in the 1st year and 0.2 for each successive year.

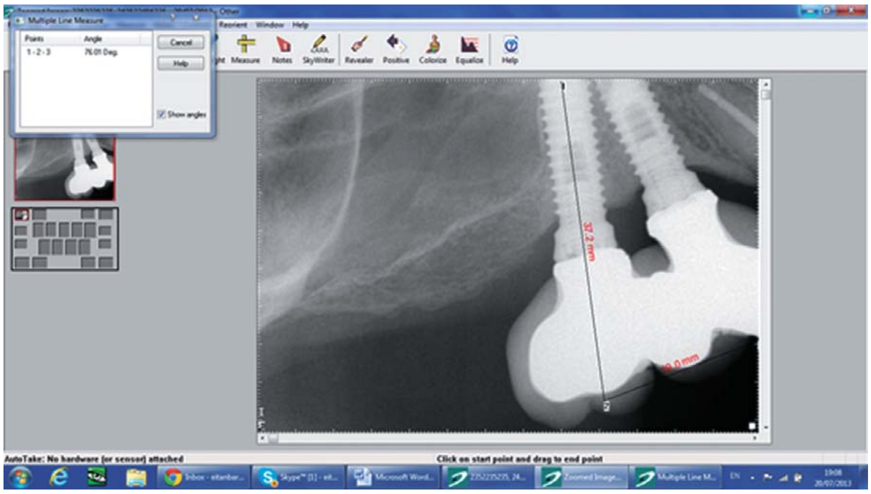

Figure 10 Implant angulation was calculated by reducing the angle between the long axis of the implant (line 1–2) and the occlusal plane (line 2–3) from 900.

between 0 and 8 degrees (mean 3.45, SD = 2.31 degrees), and angulation between titled implants and the occlusal plane varied between 20 and 50 degrees (mean 32.83, SD = 7.38 degrees) (Table 3).

Follow-up time from implantation to final examination and measurement varied between 1 and 17 years (mean 4.86 years) with 13 (45%) of the patients being followed by a period of time of up for 5 years or more (Table 2).

HI

At the time of data collection, full mouth HI[19] ranged between 5% to 40% with a mean of 15%.

Prosthetic Complications. During the period of this study, prosthetic survival rate was 100%. One bridge (3.4%) was de-cemented, and two screws loosening (3.4%) occurred in the same patient. These were repaired with no further consequences.

Radiographic Bone Level

The mean bone loss at the time of ceramic bridges installation was 0.70 ± 0.71 mm for the straight anterior implant and 0.76 ± 0.68 for the tilted implants. Average bone loss after 1, 3, and 5 years was 0.89 (SD = 0.73), 1.18 (SD = 0.74), and 1.50 (SD = 0.81) respectively for axial implants, and 0.98 (SD = 0.69), 1.10 (SD = 0.60), and 1.50 (SD = 0.67) for tilted implants, with no significant correlation between implant angulation and bone loss (Table 2). No significant correlation was obtained between straight and tilted implants regarding initial and final bone loss.

TABLE 3 Angulation between Occlusal Plane and Axial and Tilted Implants

	Mean Angle	Standard Deviation	Range
Axial implants	3.45	2.31	0–8
Tilted implants	32.83	7.38	20–50

Smokers versus Nonsmokers

No significant difference in bone loss was found after 1, 3, and 5 years between nonsmokers and smokers for axial 0.76 ± 0.76, 1.17 ± 0.80, and 1.57 ± 1.04 versus 1.14 ± 0.61, 1.19 ± 0.65, and 1.44 ± 0.53 (Table 4), neither for tilted implants 0.84 ± 0.69, 1.09 ± 0.58, 1.60 ± 0.71 versus 1.24 ± 0.62, 1.12 ± 0.62, 1.41 ± 0.62 for smokers after 1-, 3-, and 5-year follow-up, respectively (Table 4).

No significant correlation was obtained between implant angulation and annual bone loss for axial implants (Pearson $r = -0.098$, $p = .615$; however, a significant correlation was obtained for tilted implants ($r = 0.52$, $p = .004$).

Women and men did not statistically differ in annual bone loss for axial ($t\,[27] = 1.09$, $p = .28$) or for tilted ($t\,(27) = 0.70$, $p = .49$) implants.

Using Albrektsson and Zarb[20] criteria, the success rate was 89.6% (26 out of 29 implants) for straight and 93.1% (27 out of 29) for tilted implants (Table 2).

TABLE 4 Bone Loss in Axial and Tilted Implants of Smokers and Nonsmokers after 1-, 3-, and 5-Year Follow-Up

		Axial Implants			Tilted Implants		
		1 Year	3 Years	5 Years	1 Year	3 Years	5 Years
Nonsmokers	Mean	0.76	1.17	1.57	0.84	1.09	1.60
	Standard deviation	0.76	0.80	1.04	0.69	0.58	0.71
	n	19	11	6	19	11	6
Smokers	Mean	1.14	1.19	1.44	1.24	1.12	1.44
	Standard deviation	0.61	0.65	0.53	0.62	0.62	0.62
	n	10	9	7	10	9	7

DISCUSSION

Sinus augmentation procedure is considered the treatment of choice for implant-supported fixed rehabilitation of the atrophic posterior maxilla. However, sinus elevation procedure is not suitable for many patients due to medical or socioeconomical status. The use of TID offers a relatively simple alternative to restore the atrophic posterior maxilla by a freestanding implant-supported fixed partial denture, using a simplified surgical procedure, reduced morbidity, time, and cost. The present retrospective evaluation did not show a difference between marginal bone loss associated with tilted implants and axially positioned implants at any time period.

This study indicates that a fixed prosthesis supported by two implants, one of which is tilted distally, is an accepted solution for patients with limited bone volume in the posterior maxilla due to sinus pneumatization and alveolar bone loss. The study demonstrated no relationship between implant inclination and peri-implant bone loss during the functional loading period of time (4.86 ± 3.83 years). This treatment modality has previously been shown to be predictable and cost-effective for restoring the atrophic, partially edentulous posterior maxilla.[4] It has been claimed that since the procedure enables placing longer implants, it is suitable in areas of extreme masticatory loading.[4] The present success rate of the tilted implants and of the axial implants (93.1% and 93.1%, respectively) is in agreement and further supports the claim that tilted implants achieve similar success and survival rates compared with perpendicular implants'.[4,13–18]

The present findings that peri-implant crestal bone loss associated with axial and tilted implants (1.18 after 3 years and 1.5 after 5 years; and 1.1 after 3 years and 1.50 after 5 years) are in accordance with other reports in which marginal bone loss around tilted and axially positioned implants is similar over 3 to 5 years follow-up period of time.[15,17,18] Taken together, the present results suggest that under functional loading conditions, nonaxial-positioned implants incorporated in implant-supported fixed partial prostheses (FPPs) do not face a greater risk for marginal bone loss compared with axial-positioned implants. However, this should not extrapolate the findings to tilted single-implant replacement since loading conditions and vectors may be different for such implants compared with implants supporting FPPs. Celletti found no significant difference between axial and angled single freestanding implant abutments for deflection, rotation, and torque required to loosen abutment screws.[21] Based on these findings, it has been proposed that under certain conditions, implant placement in an angulated position is an advantage (i.e., enabling to make use of the greatest available bone volume). Similarly, when incorrect jaw relations exist, angulated abutments enable mesio-distal or bucco-lingual alignment at the time of restoration.[11]

There has been some concern whether restoration of implants with angulated abutments may increase lateral occlusal forces vectors.[13] Strain gauge measurements have shown higher compressive strain concentration in the coronal zone of the implant when 15° and 25° angulated abutments were used as compared with a straight abutment.[7] A finite element study concluded that most of the strain produced on cancellous and cortical bone was within the range that has been reported to increase bone mass and mineralization.[5] In this respect, Martin and Burr[10] ranked the biological response of bone to compressive forces as follows: physiological load: 200 to 2,500 μ strains; overload: 2,500 to 4,000 μ strains; and pathological load: greater than 4,000 μ strains. Nerveless, most studies reported that although an increase stress on implants exists if angled abutments are used, these increases are within physiological limits.[5,11] Peri-implant bone reactions as a consequence of excessive nonaxial or para-functional loading have been studied in animal experiments.[22–27] Although these studies were designed to evaluate excessive loading conditions that may not be comparable with physiological functional human conditions, in most studies referred to, the loading did not result in increased marginal bone destruction. This observation was also confirmed histologically in an animal study which failed to reveal any adverse effect on surrounding bone when preangled and straight abutments were compared.[21] Besides loading, several other factors were suggested to contribute to an increased rate of peri-implant bone loss (e.g., smoking[28,29] jaw of treatment,[30] implant and abutment length,[30] and type of prosthetic material as well as antagonist used).[30,31]

Although the successful use of tilted implants is an evidenced-based clinical therapy, only few articles[13–15,32] described the technical complications associated with this treatment modality. A 5-year retrospective study revealed no increased incidence of technical complication (implant fractures, crown–screw loosening, and porcelain fractures) with tilted implants when axial and nonaxial-positioned implants were used to support fixed partial dentures.[32]

Another 3-year multicenter study, 14 on 63 maxillary and 10 mandibular fixed prosthesis in which angulated abutments or a combination of angulated and standard abutments was used to support fixed prostheses, has shown that prosthodontic complication such as fracture of the occlusal material or framework, and screw loosening occurred in less than 5% of the patients.[14]

In contradiction to the abovementioned study,[14,32] Aparicio and colleagues[15] described a total of 55.2% of mechanical incidences (screw loosening was the main complication) when a combination of tilted and axially placed implants where used to support FPP (87%) during the first year. In agreement with Balshi[14] and Wennstrom and colleagues,[32] the prosthetic complications in our study (2/58 abutment loosening 3.4% and 1/29 bridge de-cementations 3.4%) were minimal. This minimal rate of complication relative to the high prosthetic complications ratio described by Aparicio and colleagues[15] may be explained by a meticulous prosthetic protocol in the present study including occlusal adjustment, narrow occlusal plane, and calibrated screw tightening at 32 N cm applied in the present study. Furthermore, all implant-supported FPPs were carefully designed with respect to occlusal loading in order to minimize the risk for excessive loading, particularly for FPPs including a posterior cantilever. Like the abovementioned studies,[14,15] the present study was limited to pairs of implants, one of which was axial and one tilted, connected with solid precise restorations which distribute the occlusal forces in much more favorable directions.[33]

The present study found no deterioration of the surrounding tissues or bone associated with tilted implants although within the tilted implant group, a positive correlation existed between increased angulation of the implants and bone loss.

It is noteworthy that some of the previous reports investigated the effect of loading of more extreme nonaxial-positioned implants on peri-implant bone level stability[4,14–16] and concluded that tilted positioning of implants does not render an increased risk for bone loss after functional loading. The positive correlation between implant angulation of tilted implants and bone loss within the tilted implant group – in the present study compared with other studies[14,16] concluding that angulation of implants renders no risk for bone loss – may be explained by the long-term follow-up (mean 4.86 years) period in the present study.

Tilted implant placement simplifies treatment procedures, reduces surgical invasion, allows longer implants to be placed with improved bone anchorage, shortens treatment time, and reduces cost-constituting benefits for the patient and the clinician. Tilted implants may therefore provide an acceptable solution also to partially edentulous patients and ill-fitting dentures that refuse implants because they worry of the surgical risks.

Our data implies that there are no clinically evident physiologic disadvantages to the use of angled implants, which are connected to adjacent axial implants, aiming to support a prosthesis restoring the posterior atrophic edentulous maxilla.

In the interpretation of the results of this study, one should recall that the classification of axial- and nonaxial (tilted)-positioned implants was related to the implant's direction relative to the occlusal plane in the mesio-distal direction only.

CONCLUSION

Implants installed at an angle to the occlusal plane may be a viable option for the rehabilitation of the atrophic maxilla. The TID approach should be considered as an option of rehabilitation of the partially edentulous posterior maxilla with extensive bone deficiency.

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