Clinical Experiences of Computer Numeric Control–Milled Titanium Frameworks Supported by Implants in the Edentulous Jaw: A 5-Year Prospective Study

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ABSTRACT

Background: Few long-term follow-up studies on treatment concepts using computer numeric control–milled titanium frameworks have been conducted.

Objective: To evaluate the clinical and radiographic performance of implant-supported prostheses provided with computer numeric control–milled titanium frameworks in the edentulous jaw and to compare their performance during the first 5 years of function with that of prostheses provided with conventional cast gold alloy frameworks.

Materials and Methods: A consecutive group of 126 edentulous patients were randomly provided with 67 prostheses with titanium frameworks (test group) in 23 upper jaws and 44 lower jaws and with 62 conventional prostheses with gold alloy castings (control group) in 31 upper jaws and 31 lower jaws. Clinical and radiographic 5-year data were collected for the test and control groups.

Results: The frequency of problems was low, and clinical and radiologic performances were similar in both groups. In the test group, the 5-year cumulative survival rates (CSRs) were 94.9% and 98.3% for implants and titanium prostheses, respectively. The respective corresponding CSRs for the control group were 97.9% and 98.2%. More loaded implants were lost in the maxillas in the test group ($p < .01$), but this difference was not significant on the patient/prosthesis level ($p > .05$). Smokers lost more implants than nonsmokers lost ($p < .01$). Similar survival rates were observed for implants in the mandible. One prosthesis was lost in each group because of the loss of implants. Metal fractures were seen only in the control group, and resin veneer fractures were more frequent in the maxilla in the gold alloy group ($p < .05$). In the test group, the mean marginal bone loss was 0.5 mm (SD, 0.44) in the maxilla and 0.4 mm (SD, 0.50) in the mandible. A similar pattern of bone reaction was observed in the control group. Mean marginal bone loss was similar for smokers and nonsmokers ($p > .05$).

Conclusion: Computer numeric control–milled titanium frameworks are a viable alternative to gold alloy castings in the edentulous jaw and present clinical and radiologic performances similar to those of conventional gold alloy frameworks during the first 5 years of function.

KEY WORDS: computer numeric controlled, CNC, implant-supported, prostheses, titanium

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For more than 15 years titanium frameworks have been used as an alternative to gold alloy castings to provide edentulous and partially edentulous patients with fixed prostheses supported by osseointegrated implants.[1–13] The rationale for using titanium instead of conventional casting alloys can be considered in relation to the relatively low cost of titanium and the fact that the metal is well tolerated in biologic environments,

as was shown in an experimental study in which mucosal attachments were formed to titanium abutments but were absent at gold abutments.[14] Supraconstruction in titanium also reduces the number of metals introduced into the oral cavity. Furthermore, titanium allows for other techniques for framework fabrication, such as laser welding of premachined titanium framework components[1–5,13] or the use of computer numeric controlled (CNC) milling procedures.[6,10] These alternative techniques may allow better control of distortion,[13,15] which is induced by conventional casting procedures.[15] A digitized fabrication process also provides alternative ''platforms'' on which the fabrication of the CNC framework could be based.[16,17] A recent in vitro study showed that a ''digital platform'' (created through three-dimensional photogrammetry) could be an accurate alternative to a conventional ''impression/plaster model platform'' when producing frameworks.[16] This option was tested in a clinical pilot study, with encouraging results.[17]

Several modifications of the design of premachined titanium framework components have been tested.[1–10] These changes were made mainly to improve the industrial process as well as the precision and the mechanical strength of the framework.[3,8,15] Follow-up studies have indicated that the titanium prostheses compare favorably with those made by conventional casting techniques, and few biologic problems have been reported for their use in the treatment of the edentulous jaw.[5,12] However, the early generations of laser-welded titanium frameworks showed a higher incidence of fractures when compared with conventional cast frameworks, especially in relation to the welding joints at the terminal abutments.[8] To reduce the risk of fractures of the frameworks, a CNC milling procedure to machine a one-piece metal frame in titanium was developed,[6] and early clinical experience was that these titanium frameworks show a clinical performance similar to that of conventional cast frameworks during the first 3 years of function.[9,12]

The purpose of the present study was to report the 5-year clinical and radiographic performance of CNC-milled titanium prostheses supported by implants and to compare the results of this treatment with the results of treatment with conventional cast gold alloy frameworks in the edentulous jaw. It was hypothesized that the titanium frameworks would be comparable with the gold alloy frameworks.

MATERIALS AND METHODS

Patient Inclusion

This was a prospective 5-year follow-up study performed at one clinic (The Brånemark Clinic, Göteborg, Sweden). Edentulous patients were consecutively provided with fixed implant-supported prostheses after abutment connection from November 1996 to February 1998. Patients receiving bone grafts or participating in other clinical studies that could affect either the design of the prosthesis or the follow-up protocol were excluded. One hundred twenty-six patients fulfilled the criteria to be included in the study. These patients were randomly provided either with titanium frameworks (test group) or with conventional cast gold alloy frameworks (control group) as described in two earlier publications.[9,12] The study started with prosthesis insertion, but data on all installed implants are also given. The ethical board at Göteborg University approved the study.

Test Group

The test group comprised 65 patients (32 women and 33 men) with a mean age of 66.8 years (standard deviation [SD], 10.8; range, 49–85 years) at the time of first surgery. Twenty-three prostheses were placed in maxillas, and 44 prostheses were placed in mandibles. Two patients were treated in both jaws.

No general health problems were reported for 26 patients (40%). Thirteen patients were medicated for cardiovascular problems, 11 patients had allergies, and 23 patients had other general health problems. Twenty-one patients (32%) reported smoking habits. The status of the opposite jaw at the time of implant placement is shown in Table 1.

Bone quality and bone resorption of the treated jaws (Table 2) were classified ad modum Lekholm & Zarb at the time of first surgery.[18] In total 368 implants were placed, supporting 334 standard abutment cylinders, 28 angulated abutments, and 2 EsthetiCone™ abutments (Nobel Biocare AB, Göteborg, Sweden). For 58 patients implant surgery was performed according to standard two-stage surgical procedure[19]; two of these patients were treated in both jaws. Seven patients received implants in the edentulous mandible according to a one-stage surgical protocol.[20] In the upper jaw 6 to 8 (mean, 6.7; SD, 0.9) Brånemark System® implants (Nobel Biocare AB) were placed, and 4 or 5

Table 1 Status of the Opposite Jaw at the Time of Implant Placement

	Test (CNC)	Control (Au)
Status	Maxilla/Mandible 44/23	Maxilla/Mandible 31/31
Complete denture	25/1	13/2
Implant-supported prosthesis	3/9	7/6
Overdenture supplemented by implant	1/0	1/0
Fixed prosthesis and natural teeth	10/9	7/16
Removable partial denture	4/4	2/5
Implant-supported prosthesis and natural teeth	1/0	1/2

Au = Gold-Alloy; CNC = computer numeric controlled.

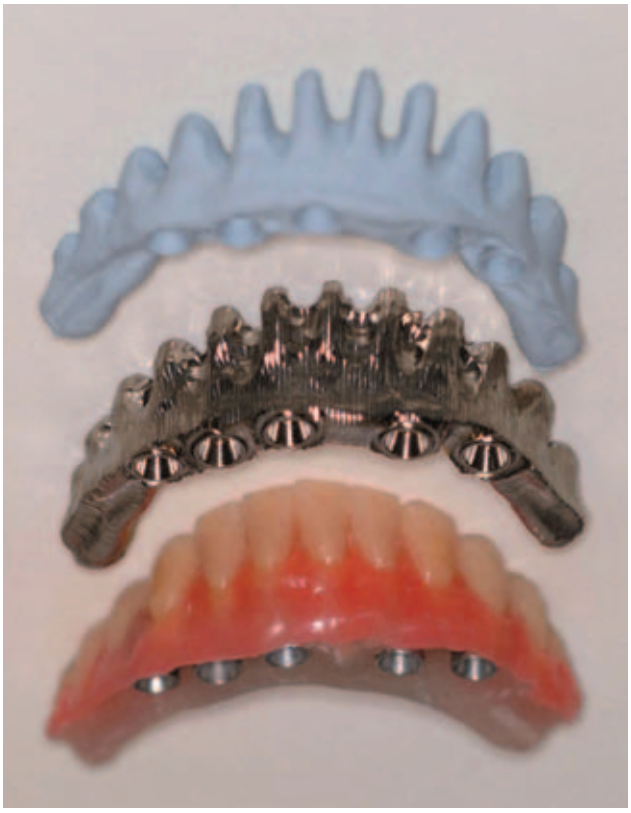

Figure 1 Stages of prosthesis fabrication. The final try-in base with artificial resin teeth (*bottom*) is the guide for fabrication of the "resin pattern" (*top*). The completed titanium framework is shown in the middle.

(mean, 4.9; SD, 0.3) Brånemark System implants were placed in the lower jaw.

The patients were provided with titanium frameworks (described elsewhere in more detail).[6] In brief, the technique for fabricating the prostheses followed the laboratory standard protocol up to the completion of the try-in of the tooth setup. Thereafter a resin pattern was made to reproduce the design of the final titanium framework (Figure 1). The shape of the plastic pattern was scanned, and precise information on the positions of the implants in the master cast was then added by measuring the master model in a coordinate measuring machine. When all the data were collected in the computer, a framework was milled as a copy of the resin pattern in one piece of grade 2 titanium (Figure 2). The titanium framework was refined and polished by the technician, and after clinical try-in, the prostheses were completed by curing resin teeth to the

Table 2 Distribution of Treated Jaws with Regard to Bone Quality and Bone Resorption According to Index by Lekholm and Zarb[18] at the Time of First Surgery

Bone Quality	Bone Resorption*				
	A	B	C	D	E
1	—	1/1	2/0	0/1	2/1
2	2/2	24/15	3/5	2/0	—
3	2/3	11/11	14/8	0/5	—
4	—	1/2	3/7	0/1	—

*Values show number of test jaws/control jaws.

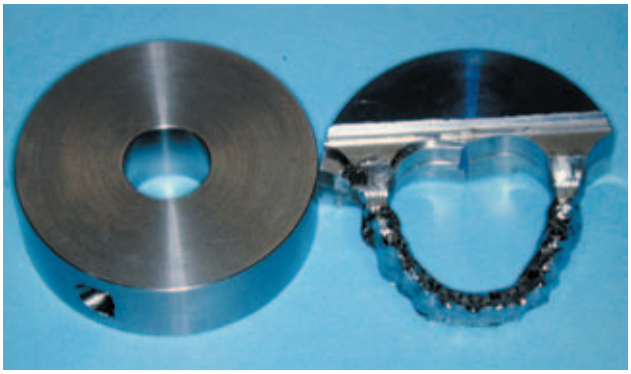

Figure 2 *Left*, a solid block of titanium. *Right*, a completed framework before separation from the block.

metal frame, following standard procedures as used for cast frameworks.[21] One manufacturer, Nobel Biocare AB, fabricated all the CNC frameworks (Procera® Implant Bridge).

After insertion and final tightening of the bridge locking screws, the patients were scheduled for check-ups for after 1, 3, and 5 years. Recalls on an individual basis were used when indicated. However, all patients were encouraged to contact the clinic whenever they had problems with their prostheses.[22,23] Intraoral apical radiography was performed at the time of prosthesis insertion and at the first and fifth annual checkups. Bone loss was measured and assessed to the closest 0.3 mm in relation to the implant reference point (placed 0.8 mm below the implant/abutment junction) on the mesial and distal sides of the implant.[24,25] A mean value between the mesial and distal sides was used in the statistical analyses.

Control Group

The control group comprised 61 patients (32 women and 29 men) with a mean age of 66.5 years (SD, 10.9 years; range, 41–88 years) at the time of first surgery. Thirty-one prostheses were placed in upper jaws, and 31 prostheses were placed in mandibles. One patient was treated in both jaws.

Twelve patients (20%) reported no general health problems. Seventeen patients were being medicated for cardiovascular problems, 19 patients were allergic, and 26 patients had other general health problems. Twenty-two patients (36%) reported smoking habits. The status of the opposite jaw at the time of implant placement is shown in Table 1.

Bone quality and bone resorption at the time of first surgery are presented in Table 2. Implant treatment was performed according to a standard two-stage surgical procedure for all patients.[19] The patients received 5 or 6 Brånemark System implants (mean, 5.1; SD, 0.3) in the edentulous mandible and 4 to 8 implants (mean, 6.5; SD, 1.2) in the edentulous maxilla. A total of 361 implants were placed, provided with 340 standard abutments, 18 angulated abutments, and one EsthetiCone abutment at a second surgical stage. Conventional fixed prostheses with cast gold alloy frameworks and resin teeth were fabricated according to standard procedure.[3,21] Annual clinical and radiographic recalls were performed in the same way as for the test group.

Registration

Data were collected on the following factors:

1. Number of patients, along with age, gender, general health, and smoking habits
2. Status of the opposite jaw
3. Bone quality and quantity
4. Number of inserted and failed implants
5. Number of clinical appointments from prosthesis insertion to 5-year checkup
6. All problems encountered during the study period after placement of the prostheses
7. Marginal bone loss

The definitions of outcome of treatment with fixed implant-supported prostheses and performance of the original prostheses during follow-up for test and control groups have been described previously by the authors.[12]

Statistics

Cumulative survival rates (CSRs) for implants and cumulative success/survival rates for prostheses were calculated according to life table techniques.[26] The Fisher exact test was used to evaluate differences for reported problems in the maxilla and mandible for the test and control groups.[26] The Mann-Whitney test was used to analyze relationships between smoking habits and bone loss.[26] The same method was used for comparing data on smoking habits and on the number of implant failures. The level of statistical significance was set at the 5% level.

RESULTS

Patients Lost to Follow-Up

Twenty-six patients (21%) were lost to follow-up during the study period (Tables 3 and 4). With the exclusion of 16 deceased patients, the follow-up rate was 92%. Altogether, 12 (18%) of the 65 patients in the test group were lost to follow-up during the study period: 6 patients died, 1 patient moved away, and the remaining 5 patients did not show up for recall appointments. One patient was withdrawn after being recorded as a failure in the test group during the second year of follow-up, owing to the loss of all six implants.

In the control group 14 patients (23%) were lost to follow-up: 10 patients died, and 4 patients did not show up for examinations. One patient was withdrawn

Table 3 Life Table Analysis of Implants and Prosthesis Placed and Lost During 5 Years and Number of Followed and Lost Patients in the Maxilla

	Placed/Examined			Failed		Lost to Follow-up			CSR	
Period	Patients	Implants	Prosth.	Implants	Prosth.	Patients	Implants	Prosth.	Implants %	Prosth. %
Test (CNC)										
1st Surgery	23	153								
Prosth. Con.	23	150	23	3					98.0	
1 Yr	22	140	22	4		1	6	1	95.1	100
2 Yr	20	126	20	6	1	1	8	1	90.5	94.9
3 Yr	19	120	19	2	-	1	4	1	88.9	94.9
4 Yr	19	120	19		-				88.9	94.9
5 Yr	17	107	17	1	-	2	12	2		94.9
					-					
Total	17	107	17	16	1	5	30	5	88.0	94.9
5 Yrs loaded									89.8	
Control Au										
1st Surgery	31	203								
Prosth. Con.	31	201	31	2					99.0	
1 Yr	29	187	29	4	1	2	10	1	96.8	96.5
2 Yr	26	173	26			3	14	3	96.8	96.5
3 Yr	25	164	25	1		1	8	1	96.6	96.5
4 Yr	23	153	23			2	11	2	96.6	96.5
5 Yr	23	153	23						96.6	96.5
Total	23	153	23	7	1	8	43	7	96.6	96.5
5 Yrs loaded									97.2	

Au = Gold-alloy; CNC = computer numeric controlled; CSR = Cumulative survival rate for implants, cumulative survival modified rate for prostheses; Prosth. = prostheses; Prosth. Con. = prostheses connection.

during the first year of follow up owing to the loss of one implant, followed by change from a fixed prosthesis to an overdenture supported by the remaining implants (see Tables 3 and 4).

Implant Stability

Altogether, 24 (3.3%) of 729 inserted implants in the test and control groups were found to be loose and were removed during the 5-year follow-up period (see Tables 3 and 4). None of these implants were one-stage inserted implants. Six implants (0.8%) were found to be loose before the prostheses had been connected, and 18 (2.5%) were removed after the prostheses had been connected. One patient with bone quality 2 and bone resorption C lost all 6 installed implants, 3 patients lost 2 implants each, and 12 patients lost 1 implant each. Seventeen of the 24 loose implants were placed in patients who were smokers, and one smoking patient lost all 6 implants. Failures were statistically more frequent in smokers as compared to nonsmokers, on the patient level ($p < .01$) as well as on the implant level ($p < .05$).

There was significantly more loss of loaded implants in the upper jaw in the test group as compared to the control group (including the patient with six lost implants) ($p < .01$). However, this difference was not observed on the patient level ($p > .05$). The failure rate was very low in the lower jaw, and no differences were found between the groups ($p > .05$). Overall 5-year implant CSRs of 94.9% and 97.9% were determined for the test group and control group, respectively.

Prosthesis Stability

One framework in the test group failed owing to the loss of all six inserted implants during the second year,

Table 4 Life Table Analysis of Implants and Prosthesis Placed and Lost During 5 Years and Number of Followed and Lost Patients in the Mandible

	Placed/Examined		Failed		Lost to Follow-up		CSR	
Period	Patients/Prosth.	Implants	Implants	Prosth.	Patients/Prosth.	Implants	Implants %	Prosth. %
Test (CNC)								
1st Surgery	44	215						
Prosth. Con.	44	214	1				99.5	
1 Yr	44	214					99.5	100
2 Yr	40	195			4	19	99.5	100
3 Yr	39	190		-	1	5	99.5	100
4 Yr	37	180		-	2	10	99.5	100
5 Yr	37	180		-			99.5	100
Total	37	180	1	0	7	34	99.5	100
Control (Au)								
1st Surgery	31	158						
Prosth. Con.	31	158					100	
1 Yr	29	148			2	10	100	100
2 Yr	27	138			2	10	100	100
3 Yr	26	133			1	5	100	100
4 Yr	24	123			2	10	100	100
5 Yr							100	100
Total	24	123	0	0	7	35	100	100

Au = Gold-alloy; CNC = computer numeric controlled; CSR = cumulative survival rate for implants, cumulative success rate for prostheses; Prosth. = prostheses; Prosth. Con. = prostheses connection.

and the patient received a denture in the upper jaw instead (see Table 3). During the third year, one prosthesis in the test group was shortened because of the loss of two implants in the maxilla, and the patient received a partial removable denture retained by the implant-supported prosthesis. Another titanium prosthesis in the upper jaw was shortened owing to the loss of one implant during the fifth year. The two shortened prostheses were recorded as "survival, modified" (Table 5). No framework fractured in the test group.

In the control group, one prosthesis was removed from an upper jaw because of the failure of one implant during the first year and was replaced by an overdenture supported by the four remaining implants (see Table 3). Another prosthesis in the control group was shortened because of an implant failure. Two frameworks fractured in the control group but were resoldered and maintained in function (listed as "survival, modified" in Table 5). The difference in fracture rate was not statistically significant ($p > .05$).

Overall 5-year prosthesis CSRs (survival, modified) of 98.3% and 98.2% were found for the test group and control group, respectively.

Follow-Up Maintenance

The distribution of patients with regard to the number of clinical appointments per year is presented in Table 6. Few patients required an extensive number of appointments to maintain the prostheses. On average, patients in the test group and the control group visited the clinic for checkups and maintenance 1.3 times (SD, 1.3) and 1.4 times (SD, 1.4) per year, respectively, during the 5-year follow-up period.

Twenty-two patients (34%) in the test group had no problems at all with their prostheses or implants during the postinsertion period. In the control group 16 patients (26%) reported no problems. The frequency of problems was low, and fewer problems were observed in the mandible. More resin veneer fractures in the upper jaw were reported in the control group than in the test group ($p < .05$). Because of acrylic-tooth

Table 5 Outcome of Treatment with Fixed Implant-Supported Prostheses and Performance of Original Prostheses after 5 years of Follow-up in the Mandible and Maxilla

	Fixed Prosthesis Treatment				Original Prosthesis Performance			
	Test		Control		Test		Control	
	n	%	n	%	n	%	n	%
Maxilla								
Success	17	73.9	23	74.2	15	65.2	17	54.8
Survival	0		0		0		3	9.7
Survival modified					2	8.7	3	9.7
Failure	1	4.3	1	3.2	1	4.3	1	3.2
Withdrawn	5	21.7	7	22.6	5	21.7	7	22.6
Mandible								
Success	37	84.1	24	77.4	37	84.1	24	77.4
Survival	0		0		0		0	
Survival modified					0		0	
Failure	0		0		0		0	
Withdrawn	7	15.9	7	22.6	7	15.9	7	22.6

n = number of prostheses.

fractures, the veneers on three maxillary prostheses in the control group had to be exchanged in the laboratory during the second, third, and fifth years, respectively. One of these prostheses also received an "occlusal table" of gold alloy on the palatal side (listed as "survival" in Table 5). Also, losses of fillings at the screw site were more common in the maxilla in patients in the control group ($p < .001$). No statistical significances for reported problems in the mandible were found between the test and control groups ($p > .05$) (Table 7).

Radiography

Mean marginal bone levels and mean marginal bone losses are presented in Tables 8 and 9. No statistically significant differences between test and control groups

Table 6 Distribution of Patients with Regard to Number of Clinical Appointments per Year (%)

	Follow up	No. of Appointments per Year (%)					
Year	No.of Patients (Test/Control)	0	1	2 to 4	5 to 7	8 to 10	>10
Maxilla							
1	22/29	5/0	0/0	86/79	0/14	5/7	5/0
2	20/26	40/15	45/58	5/8	5/8	0/4	5/8
3	19/25	0/0	74/76	21/8	0/8	5/8	0/0
4	19/23	68/65	26/22	5/13	0/0	0/0	0/0
5	17/23	0/0	82/91	12/9	6/0	0/0	0/0
Mandible							
1	44/29	0/3	0/0	98/93	0/3	2/0	0/0
2	40/27	50/41	42/56	8/4	0/0	0/0	0/0
3	39/26	8/12	79/77	10/8	3/4	0/0	0/0
4	37/24	68/88	24/12	8/0	0/0	0/0	0/0
5	37/24	0/0	95/92	5/4	0/4	0/0	0/0

Table 7 Distribution of Reported Problems for the CNC and Au Group During 5 Years in Function

	Number of Occurences, Number Of Patients Within Brackets			
	Test (CNC)		Control (Au)	
Problem	Maxilla 23	Mandible 44	Maxilla 31	Mandible 31
Resin veneer fracture*	10 (8)	2 (2)	23 (10)	3 (3)
Soft-tissue inflammation	1 (1)	3 (2)	3 (3)	2 (2)
Cheek/lip biting	0	2 (2)	0	2 (2)
Implant loss before insertion	3 (2)	1 (1)	2 (2)	0
Implant loss after insertion	13 (6)	0	5 (5)	0
Loss of access hole filling	3 (3)	4 (4)	23 (15)	5 (5)
Speech problem	2 (2)	0	1 (1)	0
Loose screws/Fracture screws	0	0	0	0
Implant component fracture	0	0	1 (1)	0
Framework fracture	0	0	2 (2)	0
Other problems	10 (8)	7 (7)	4 (4)	6 (5)

Au = Gold-alloy; CNC = computer numeric controlled.
*All resin veneer fractures except 2 in test group and 3 in control group were mended at the laboratory.

or between smokers and nonsmokers could be shown ($p > .05$).

DISCUSSION

The present study showed an overall good treatment result indicating mainly similar clinical and radiologic performance for the two types of frameworks. Only one implant failed in the edentulous mandibles, and this low frequency of implant failure in the lower jaw is in accordance with other studies with similar groups of patients.[8,27] All implants lost after prosthesis placement were lost from the maxilla. This pattern of more implant failures in the upper jaw is well documented and is also in accordance with other studies.[22,28,29] Another observation that corroborates other studies is that implants may occasionally be lost in clusters in the upper jaw.[11,30] Thus, in this study one patient in the test group lost all six implants during the second year, and the number of loose implants was thereby significantly increased for this group of patients. As no significant difference in implant survival between titanium and cast frameworks has been shown in earlier comparable studies[5,8] and as no other signs of different biologic responses to titanium frameworks have been

Table 8 Mean Marginal Bone Level in Relation to the Radiographic Implant Reference Point (mm) Mean Marginal Boneloss During the First Year and the Entire 5-Year Follow Up Period, Calculated by Means of Intra-individual Comparisons (mm)

	Bonelevel						Boneloss	
	Loading		After 1 Year		After 5 Years		0 to 1 Year	0 to 5 Years
Group	n	Mean (SD)	n	Mean (SD)	n	Mean (SD)	Mean (SD)	Mean (SD)
Maxilla								
Test (CNC)	22	0.9 (0.46)	20	1.2 (0.60)	16	1.2 (0.6)	0.4 (0.35)	0.5 (0.41)
Control (Au)	31	0.9 (0.66)	29	1.2 (0.69)	23	1.2 (0.49)	0.3 (0.31)	0.4 (0.45)
Mandible								
Test (CNC)	44	0.4 (0.36)	44	0.8 (0.43)	37	0.9 (0.55)	0.4 (0.33)	0.4 (0.50)
Control (Au)	31	0.4 (0.45)	28	0.8 (0.55)	24	1.1 (0.64)	0.4 (0.40)	0.7 (0.54)

Au = Gold-alloy; CNC = computer numeric controlled.

Table 9 Numbers of Implants with Regard to Bone Level (mm) after 5 Years and Bone Loss (mm) During 5-Years Follow-up for Individual Implants

	Bone Level After 5 Years				Bone Loss During 5 Years			
No. of Implants:	Test		Control		Test		Control	
mm	Mandible	Maxilla	Mandible	Maxilla	Mandible	Maxilla	Mandible	Maxilla
0*	43	15	25	20	76	38	37	67
< 0.5	19	4	5	4	28	14	13	18
0.5–1.0	38	17	18	28	34	27	19	33
>1.0–1.5	54	35	49	68	31	14	37	30
>1.5–2.0	15	25	14	24	5	14	10	5
>2.0–2.5	4	4	8	11	3		4	
>2.5–3.0	5	3	1	1	2		2	
>3.0–4.0	2	4	1	1	1			
>4.0–5.0			2				1	
Total	180	107	123	153	180	107	123	153

*Increased bone level is registered as 0 mm.

observed in this study, the significant difference in implant survival between test and control groups in the present study should rather be attributed to factors other than the design or material of the titanium framework. Instead, the cluster pattern in this study may be related more to smoking habits, which have been shown to be the cause of significant increases of implant failures in other studies as well.[30–33]

The biologic response to treatment (reflected as bone loss during the follow-up period) was favorable, and there were low levels of average bone loss (see Tables 8 and 9). Bone loss in the upper and lower jaws was similar for the two groups and was well in accordance with earlier studies.[8,11,34,35] No statistical difference in bone loss could be observed between smokers and nonsmokers in the present study. This result could not confirm earlier reported correlations between bone loss and smoking habits.[30,36] Furthermore, it is possible to observe that the overall number of implants with bone levels placed 2 mm below the reference point after 5 years and implants with > 2 mm of bone loss after 5 years are not the same in the present material (see Table 9). Accordingly it seems important to report both bone levels and bone losses of individual implants so as to allow full information on this aspect. Altogether 47 of 563 implants (8.3%) presented a bone level that was > 2 mm below the reference point after 5 years of follow-up, but only 13 (2.4%) of the implants showed a bone loss of > 2 mm during these 5 years (see Table 9). The interpretation of this must be that some implants heal with a bone level that is already placed below the reference point from the start. Accordingly, the observation of an ongoing bone loss indicating a possible periimplantitis[37] was rare in the present study, which is in accordance with some reports[8,27] but not with others, indicating a higher incidence of bone loss.[23]

Two major reasons for using this CNC one-piece milling technique were to reduce the risk of metal fractures and to reduce the cost of the material in the framework. Earlier studies on laser-welded titanium frameworks indicated significant problems with framework fractures, basically related to the welding joints at the terminal abutments.[2,5,8] The present results show no fractures at all with this one-piece technique, which is in accordance with another follow-up study on the same type of framework.[38] Accordingly, it is reasonable to assume that the risk of fractures of titanium frameworks is clearly reduced by replacing laser-welding procedures with a one-piece milling technique. Also, as regards fractures, frameworks produced with this CNC milling procedure compare favorably with cast frameworks. Since titanium and gold alloy basically have comparable levels of strength, the observed difference in framework fractures may be related to design rather than to metal strength. When working with gold alloy frameworks, technicians may make wax-ups with more slender dimensions than they would with the more inexpensive titanium, to reduce cost. If this is the case, the technician will also increase the dimensions of

the titanium framework for better support of the veneering material and for deeper screw access holes. These differences in design and dimensions may have a relation with the lower incidence of framework fractures, but they also may play an important role in significantly reducing the risk of veneer fractures ($p < .05$) by means of better metal support as well as reducing the risk of loose access hole fillings ($p < .05$) by means of deeper metal screw access holes and better retention for the composite resin.

Few mechanical problems were recorded for the implant components, and no fractures in the one-piece titanium frameworks were reported, observations that compare favorably with those of other studies.[5,8,11,22] Compared to groups in other studies,[8,22,23] patients in the present test group needed fewer appointments for maintenance during the first year as well as during the following 4 years of follow-up, and the pattern of visits was similar for the control group. This could be taken as an indication that the present treatment protocol of restoration with implants in edentulous patients has reached a steady-state level except for the resin veneer fractures. As discussed above, more fractures of resin veneers were seen in the control group, and the fractures were more common in the upper jaws for both groups, as was also reported earlier.[5,11,22] However, early experiences with titanium frameworks showed significantly greater problems with veneer fractures when compared to gold alloy frameworks.[5] The situation today is the opposite, indicating improvement as a result of learning.[10] Nevertheless, improvement of the supraconstruction, whatever metal has been used, has to be made with better acrylic resin matrix and interocclusal metal on the palatal side of the upper jaw in patients affected with overloading and grinding. Thus in the light of present data, long-term trends of improved implant survival,[39] reduced bone loss at implants,[39] a lower incidence of framework fractures,[40] and fewer complications and maintenance appointments[8,22] over time indicate a future for this treatment modality, with further control of the few remaining clinical problems such as veneer fractures.

CONCLUSION

Titanium frameworks made by the CNC milling technique (eg, the Procera Implant Bridge) present clinical and radiologic performances similar to those of conventional cast gold alloy frameworks in the edentulous jaw during the first 5 years of function and caused few complications during the study period. The results of this study show that titanium frameworks fabricated by CNC milling can be used as alternatives to cast frameworks for full-arch implant-supported prostheses.

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