CNC-Milled Titanium Frameworks Supported by Implants in the Edentulous Jaw: A 10-Year Comparative Clinical Study

Anders Örtorp, DDS, PhD;* Torsten Jemt, DDS, PhD†‡

ABSTRACT

Background: No long-term clinical studies covering more than 5 years are available on Computer Numeric Controlled (CNC) milled titanium frameworks.

Aim: To evaluate and compare the clinical and radiographic performance of implant-supported prostheses provided with CNC titanium frameworks in the edentulous jaw with prostheses with cast gold-alloy frameworks during the first 10 years of function.

Material and Methods: Altogether, 126 edentulous patients were by random provided with 67 prostheses with titanium frameworks (test) in 23 maxillas and 44 mandibles, and with 62 prostheses with gold-alloy castings (control) in 31 maxillas and 31 mandibles. Clinical and radiographic 10-year data were collected for the groups and statistically compared on patient level.

Results: The 10-year prosthesis and implant cumulative survival rate was 95.6% compared with 98.3%, and 95.0% compared with 97.9% for test and control groups, respectively ($p > .05$). No implants were lost after 5 years of follow-up. Smokers lost more implants than nonsmokers after 5 years of follow-up ($p < .01$). Mean marginal bone loss in the test group was 0.7 mm (SD 0.61) and 0.7 mm (SD 0.85) in the maxilla and mandible, with similar pattern in the control group ($p > .05$), respectively. One prosthesis was lost in each group due to loss of implants, and one prosthesis failed due to framework fracture in the test group. Two metal fractures were registered in each group. More appointments of maintenance were needed for the prostheses in the maxilla compared with those in the mandible ($p < .001$).

Conclusion: The frequency of complications was low with similar clinical and radiological performance for both groups during 10 years. CNC-milled titanium frameworks are a viable alternative to gold-alloy castings for restoring patients with implant-supported prostheses in the edentulous jaw.

KEY WORDS: bone loss, complications, framework design, implant-supported, long-term follow-up, mandible, maxilla, prostheses

INTRODUCTION

Titanium frameworks have for more than 20 years been used as an option to gold-alloy castings to restore edentulous patients with screw-retained implant-supported prostheses.[1–10] The advantages of using titanium with high biocompatibility, good resistance to corrosion, and very low allergic potentials[2,5,11] are well documented in both clinical[6,7,9] and experimental studies.[12,13] The titanium superstructure reduces the number of metals introduced in the mouth, and the material allows for other techniques for framework fabrication with premachined components, or by using Computer Numeric

*Associate professor, Odont.Dr, Prosthodontist, Department Prosthetic Dentistry/Dental Materials Science, Institute of Odontology, The Sahlgrenska Academy, University of Gothenburg, Sweden; †Chairman, Prosthodontist, The Brånemark Clinic, Public Dental Health Service, Göteborg, Västra Götaland Region, Sweden; ‡professor, Odont.Dr, Department Prosthetic Dentistry/Dental Materials Science, Institute of Odontology, The Sahlgrenska Academy, University of Gothenburg, Sweden

Reprint requests: Dr. Anders Örtorp, Department Prosthetic Dentistry/Dental Materials Science, Institute of Odontology, Box 450, S – 405 30 Göteborg, Sweden; e-mail: anders.ortorp@vgregion.se

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Controlled (CNC) milling procedures.[4,6,14] These techniques may allow for better control of distortion[1,4,8], that is induced by conventional casting procedures.[1] A digitalized fabrication process also provides digital "platforms," from which the fabrication of the CNC framework could be based upon which opens up for alternatives to conventional impressions in the future.[15,16]

Clinical studies have indicated that the titanium prostheses compare favorably with casting techniques.[7,9,14,17,18] However, the early generations of laser-welded titanium frameworks showed higher incidence of fractures mainly in relation to the welding joints compared with cast frameworks.[9] To reduce the risk of fractures, a CNC milling procedure to fabricate one-piece titanium frame was developed,[4,14] and early clinical reports shows that these frameworks have similar clinical performance as conventional cast frameworks during the first 5 years of function in the edentulous jaw.[17,18] However, no study longer than 5 years of follow-up is published on CNC-milled frameworks[18], and as fracture problems are related to fatigue and time, longer follow-up periods would be of interest.

The aim of the present study was to report the 10-year clinical and radiographic performance of CNC-milled titanium prostheses supported by implants, and to compare the result with patients provided with cast gold-alloy frameworks in the edentulous jaw. It was hypothesized that the milled titanium frameworks would be comparable with the gold-alloy frameworks.

MATERIALS AND METHODS

Altogether, 1,477 edentulous patients were referred to the Brånemark Clinic (Göteborg, Sweden) for prosthetic consultation or treatment from November 1996 to February 1998. Two hundred and four of these patients were treated with fixed implant-supported prostheses in the edentulous jaw, where 78 patients (38%) were excluded from this study. Reasons for exclusion were that the patients were not following routine clinical protocol, because they had either received bone grafts in the maxilla, changed removable to fixed prostheses or participated in other clinical studies that either affected the design of the prosthesis or the follow up protocol. The remaining 126 patients were clinical routine patients treated with fixed screw-retained implant-supported abutment level prostheses in the edentulous maxilla and mandible during this period. Basically every paired patient was provided with a conventional cast framework, and the unpaired 65 patients were provided with a CNC-milled titanium frameworks. The present prospective 10-year follow-up study covers the same patient material as earlier reported in previous publications.[14,17,18] The study populations have earlier been described with regard to (Table 1) inclusion criteria, status of the opposite jaw, bone quality/resorptions of the treated jaw.[14,17,18] One hundred and twenty-six patients were at random provided with either CNC-milled titanium (CNC; test; Figure 1) or cast gold-alloy frameworks (Au; control).[14,17,18] The study starts with prosthesis insertion, but data on all installed implants are also given (Table 1).

TABLE 1 Distribution of Treated Jaws, Installed Implants, and Prostheses for Computer Numeric Controlled (CNC) and Gold-Alloy (Au)

Jaw	Prostheses	Brånemark System® Implants
CNC (test)		
Maxilla	23	152
Mandible	44	215
Total	67*	367
Au (control)		
Maxilla	31	203
Mandible	31	158
Total	62†	361
Total test and control	129	728

*Two patients were treated in both jaws.
†One patient was treated in both jaws.

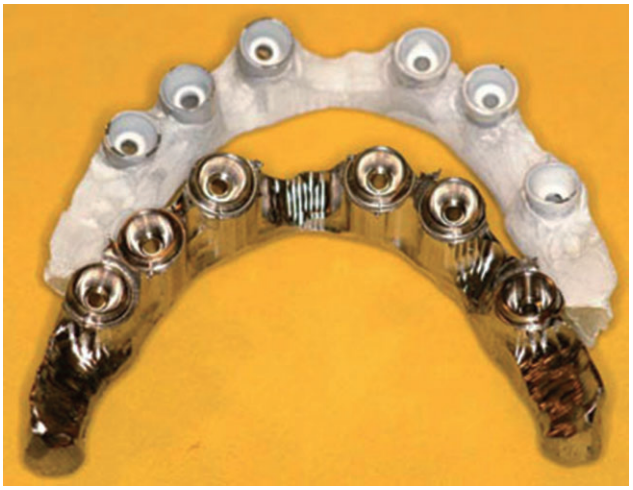

Figure 1 The final try-in base with artificial resin teeth is the guide for fabrication of the resin framework pattern (upper). Completed milled titanium framework before refinement and polish (lower).

The test group comprised 65 patients, 32 women and 33 men with a mean age of 66.8 (SD 10.8, range 49–85) years at the time of first surgery. Twenty-one patients (32%) reported smoking habits (34% for all included patients).

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 mandible according to one stage surgical protocol.[20] In the maxilla and the mandible, six to eight (Mean 6.7, SD 0.9) and four or five (Mean 4.9, SD 0.3) Brånemark System® implants with turned surfaces (Nobel Biocare AB, Göteborg, Sweden) were placed, respectively. One hundred eighty standard, 179 Mk2 and 8 Wide Platform implants were used.

The patients were, at random, consecutively provided with CNC-milled grade 2 titanium frameworks (Procera® Implant Bridge, Nobel Biocare AB) supporting resin teeth as veneers as described elsewhere (Figure 1).[4,14]

The control group comprised 61 patients, 32 women and 29 men with a mean age of 66.5 (SD 10.9 years, range 41–88) years at the time of first surgery (Table 1). Patients in this group were at random included from the total group of edentulous patients, provided with gold-alloy frameworks, as described earlier.[14,17,18] Twenty-two patients (36%) reported smoking habits. Implant treatment was performed according to standard two-stage surgical procedure for all patients.[19] One patient was treated in both jaws.[14,17,18] The patients received five or six Brånemark System® implants (mean 5.1, SD 0.3) in the mandible and four to eight implants (mean 6.5, SD 1.2) in the maxilla. All the implants had turned surfaces with 177 standard implants and 184 Mk2 implants. Prostheses with cast gold-alloy frameworks and resin teeth were fabricated according to standard procedures.[1]

All edentulous patients provided with fixed prostheses supported by implants were followed-up according to the same strict protocol. Accordingly, the patients were scheduled for check-ups after 1, 3, 5, and 10 years. Recalls on an individual basis was used when indicated, and the patients contacted the clinic whenever they had problems with their prostheses.

Radiographic examinations were by routine performed in the specialist clinic for Oral and Maxillofacial Radiology (Göteborg, Sweden) by using intra-oral apical radiographs, scheduled after prosthesis placement and after 1, 5, and 10 years in function. However, some few patients declined radiographic examinations due to various reasons.

Marginal bone levels were measured in relation to the fixture-abutment junction as a newer standard, placed 0.8 mm coronal to the radiographic reference point, used in a previous study.[14] Intra- and inter-individual precision of radiographic measurements has been reported in another study,[21] and bone levels were related to the implant threads to the closest 0.3 mm.[22] Bone loss was calculated as the difference between bone levels, measured at two different occasions. A mean value between the mesial and distal side of the implant was used in the statistical analyses.[22,23]

Clinical data were collected regarding parameters accounted for more in detail in the previous studies.[14,17,18] Also, definitions of outcome of treatment have been described earlier.[17] Implant stability is calculated from the time point of implant installation. The prosthesis was considered as a failure when it was replaced by a new implant prosthesis or conventional denture, and remaining stable implants were accordingly withdrawn from the study. Prostheses were to be removed clinically to test implant stability whenever radiographic signs and/or clinical symptoms were present to suspect that an implant had lost osseointegration.[24] However, only survival criteria for implants has been used as prostheses were not removed on a routine basis to confirm osseointegration.[25,26] Prosthetic treatment using fixed prostheses in the edentulous jaw after 10 years are also

calculated as a protocol, then also using replaced prostheses to present this specific result.

Statistical Analysis

Conventional statistics (mean, SDs, and range) were used for descriptive purposes. Cumulative survival rate (CSR) for implants and prostheses have been calculated according to life table techniques, and differences in CSRs in the test and control groups were analyzed with Log-rank test.[27,28] Logistic regression was used to model the binary outcome of implant failures and parameters were obtained fitting generalized estimating equation (GEE) regression models. Differences in marginal bone level and bone loss were analyzed with the Mann-Whitney *U* test between groups. Number of implants with a bone loss of more than 1.2 mm (two threads) was analyzed by Fisher's exact test for comparison between groups for dichotomous variables and Mann-Whitney *U* test for continuous variables. To analyze relations between smoking habits and bone loss and number of implant failures, Fisher's exact test was used for comparison between groups for dichotomous variables, chi square exact test analyzed nonordered categorical variables and Mann-Whitney *U* test continuous variables. Fisher's exact test[28] evaluated differences for reported problems for the test and control group. Mann-Whitney *U* test was used to evaluate total mean appointments between groups, and to analyze differences in time between abutment operation and radiological examination of the fixtures between the groups. Statistical significance was set to $p < .05$. The tests were performed on patient/prosthesis level only.

RESULTS

Patients Lost to Follow-Up

Altogether, 52 patients (41.3%) were lost to follow-up after 10 years (Table 2) and provided with 54 prostheses. Furthermore, after 9 years, one mandibular prosthesis in the test group fractured and was recorded as a failure, but the patient remained in the study with a prosthesis in the maxilla. Twenty-four patients were withdrawn, recorded as "deceased" (Table 2), but another 14 patients, recorded to be withdrawn due to "health problems"/"no contact" were deceased at the termination of the study, according to the Swedish national population register. Accordingly, 38 patients (30.2%) were deceased during the 10-year follow-up period.

Implant Stability

Minor adjustments regarding year of failed implants have been made in Table 3 as compared with earlier published results.[14,17,18] Altogether, 24 of 728 inserted implants (3.3%) were found loose and removed during the 10-year follow-up period in test and control groups (Table 3). Detailed presentations of loss of implants during the first 5 years have been given in earlier publications.[14,17,18] In brief, no implants were lost after 5 years. Seventeen of the 24 loose implants were placed in smoking patients, and failures were more frequent in smokers as compared with nonsmokers on the patient level after 5 and 10 years of follow-up ($p < .05$).

There were no differences of loss of loaded implant observed on patient level ($p > .05$) between the two study groups after 5 and 10 years. Altogether, only one

TABLE 2 Distribution of Patients Lost to Follow-Up in the Computer Numeric Controlled (CNC) (Test) Group and the Gold-Alloy (Au) (Control) Group During 10 Years

Time	Number of Patients (CNC/Au)	Number of Patients Lost to Follow-up				Total Lost to Follow-Up (CNC/Au)
		Deceased (CNC/Au)	Moved (CNC/Au)	Health Problems (CNC/Au)	No Contact (CNC/Au)	
No. of patients	65*/61†	–	–	–	–	–
0 to 5 years	55/48	4/9	1/–	2/1	3/3	10/13
6 to 10 years	36/38	7/4	1/1	5/4	6/1	19‡/10
Total 10 years	36/38	11/13	2/1	7/5	9/4	29/23

*Two patients were treated in both jaws.
†One patient was treated in both jaws.
‡One patient (not reported here) excluded in the lower jaw remained as a patient in the upper jaw at year 9.

TABLE 3 Life Table of Prostheses and Placed Implants in the Maxilla and Mandible

	Placed/Examined		Lost to Follow-Up		Failed		CSR (%)	
Period	Prosth.	Implants	Prosth.	Implants	Prosth.	Implants	Prosth.	Implants
CNC (test)								
1st surgery	–	367	–	–	–	–	–	100
Prosthesis placement	67	361	–	–	–	6	100	98.3
1 year	66	354	1	5	–	2	100	97.8
2 years	61	329	4	19	1	6	98.3	95.9
3 years	59	318	2	9	–	2	98.3	95.3
4 years	57	307	2	11	–	–	98.3	95.3
5 years	56	300	1	6	–	1	98.3	95.0
6 years	47	256	9	44	–	–	98.3	95.0
7 years	47	256	–	–	–	–	98.3	95.0
8 years	42	227	5	29	–	–	98.3	95.0
9 years	38	207	3	20	1	–	95.6	95.0
10 years	35	189	3	18	–	–	95.6	95.0
Total	35	189	30	161	2	17	95.6	95.0
Au (control)								
1st surgery	–	361	–	–	–	–	–	100
Prosthesis placement	62	358	–	–	–	3	100	99.2
1 year	59	341	2	15	1	2	98.3	98.6
2 years	54	316	5	24	–	1	98.3	98.2
3 years	52	302	2	13	–	1	98.3	97.9
4 years	48	281	4	21	–	–	98.3	97.9
5 years	48	281	–	0	–	–	98.3	97.9
6 years	43	253	5	28	–	–	98.3	97.9
7 years	42	247	1	6	–	–	98.3	97.9
8 years	41	241	1	6	–	–	98.3	97.9
9 years	39	228	2	13	–	–	98.3	97.9
10 years	37	218	2	10	–	–	98.3	97.9
Total	37	218	24	136	1	7	98.3	97.9

CSR = cumulative survival rate; CNC = Computer Numeric Controlled; Au = gold-alloy.

implant was loose and removed in the lower jaws. This implant was lost before prostheses delivery in the test group.

An overall 10-year implant CSR of 95.0% and 97.9% for the test and control groups was presented, respectively (Table 3). The corresponding CSR for loaded implants was 96.6 and 98.7, respectively.

Prosthesis Stability

In the test group, one prosthesis failed due to loss of all six inserted implants during the second year and resumed to a denture in the maxilla (Table 3). Another prosthesis in the mandible failed after 9 years in function due to framework fracture and was replaced by a new CNC framework (Table 3). One CNC prosthesis was shortened due to loss of two implants in the maxilla after 3 years, and the patient received a partial removable denture retained by the remaining implant-supported prosthesis. Furthermore, a second prosthesis in the upper jaw was shortened due to loss of one implant during the fifth year of function. A third prosthesis fractured and was shortened at the end of 10 years follow-up in the mandible. These three shortened prostheses were recorded as "survival, modified," according to earlier definitions (including "survival modified"; 10-year CSR 95.6%).[17]

In the control group, one prosthesis was removed in the maxilla due to loss of one implant during the first year, replaced by an overdenture supported by the four remaining implants (failed prosthesis; Table 3). Another

TABLE 4 Overall Mean Number of Appointments (SD) in the Computer Numeric Controlled (CNC) (Test) Group and the Gold-Alloy (Au) (Control) Group

Follow-Up Year = Y	Protheses (CNC/Au) 67/62	Mean (SD) Number of Appointments	
		CNC (test)	Au (control)
Total maxilla 0 to 10 Y	13/17	2.0 (2.2)	1.5 (1.3)
Total mandible 0 to 10 Y	22/20	0.9 (0.4)	0.8 (0.3)
Total 0 to 10 Y	35/37	1.3 (1.4)	1.1 (1.0)

Patient level statistical comparison to the control group; no statistical significances registered ($p > .05$).
Number of prostheses at end of time interval is given.

prosthesis in the maxilla was shortened due to an implant failure after 1 year in function. Two frameworks fractured in the control group after 2 and 3 years in function, but were resoldered and maintained in function (including "survival, modified"; 10-year CSR 98.3%).[17] No failure or modification of the frameworks in the control group took place during the last 5 years of follow-up.

The 10-year prosthesis CSR for original prostheses was 89.0% and 94.4% for the test and control groups, respectively ($p > .05$). The 10-year prosthesis CSR including survival modified for maxillae/mandibles was 95.2%/95.6% and 96.5%/100% for the test and control groups, respectively ($p > .05$). Including replaced and new prostheses, the overall 10-year continuous function of a fixed prosthesis in the mandible and the maxilla reached 98.3%.

Maintenance

Few patients required an extensive number of appointments to maintain the prostheses (Table 4), and no differences were seen between study groups ($p > .05$). In total, more appointments were needed for the maxilla, with an average of 1.7 (SD 1.7) visits per year when compared with the mandible with an average of 0.8 (SD 0.4) visits per year ($p < .001$).

Twenty patients (57.1%) in the test group did not have any problems at all with their prostheses or implants during the post-insertion period of 10 years. In the control group, 14 patients (37.8%) reported no problems at all ($p > .05$). Corresponding numbers of patients who had no problems before withdrawals was 36 (55.4%) and 28 (45.9%), respectively.

The frequency of problems was low with fewer problems observed in the mandible. No differences for reported problems were found in the maxilla and the mandible between test and control groups ($p > .05$, Tables 5 and 6) at 10-year follow-up. However, resin veneer fractures were a common complication in both the test and control group in the maxilla (Table 5).

In the test group, all the veneers of seven prostheses in the maxilla had to be replaced in the laboratory during the 10 years due to acrylic teeth fractures and/or wear. Five of these prostheses also received a new "occlusal table" of gold alloy/titanium (four prostheses) or acrylic (one prosthesis) on the palatal side (Table 5, Figure 2). No prostheses in the mandible had veneers replaced due to wear in this group.

In the control group, also all the veneers of seven prostheses in the maxilla had to be exchanged in the laboratory due to acrylic teeth fractures and/or wear. Four of these prostheses also received a new "occlusal table" of gold alloy (three prostheses) or acrylic (one prosthesis; Table 5). Two prostheses in the mandible had all veneers replaced due to wear after 8 and 10 years in function, respectively (Table 6). Loss of screw site fillings were more common in the control group in the maxilla after 5 years ($p < .001$, Table 5) but not after 10 years ($p > 0.05$).

Radiographs

Sixty eight of 72 followed-up patients (94.4%) were radiographically examined at 10-year check-up, with no differences in patient distribution between the groups.

The mean time between abutment surgery and baseline radiographic examination after prosthesis placement was 89 days (SD 29.5) for the test group and 77 days (SD 35.4) for the control group ($p < .05$).

Data on mean marginal bone levels are presented in Tables 7 and 8, and data on mean marginal bone loss are

TABLE 5 Distribution of Reported Number of Problems (Prostheses Within Brackets) in the Maxilla Related to the Computer Numeric Controlled (CNC) (Test) or Gold-Alloy (Au) (Control) Groups During Different Time Intervals

Years	5 to 10 Years		0 to 10 Years	
Prostheses	CNC	Au	CNC	Au
Prostheses at start/end of time intervals	18/13	23/17	23/13	31/17
Number of observations (number of prostheses)				
Mechanical problems				
Loose prosthesis	0	0	0	1
Implant component fracture	1	0	2 (2)	1
Framework fracture	0	0	0	2 (2)
Veneer fracture: uncomplicated*	6 (6)	5 (4)	7 (6)	9 (6)
Veneer fracture: severe†	17 (8)	14 (8)	26 (11)	37 (13)
Wear of acrylic teeth	1	2 (2)	2 (1)	3 (3)
Loss of screw site filling	2 (2)	4 (3)	5 (5)	25 (10)
Biological and prosthesis problems				
Redesign occlusal metal/acrylic table	5 (5)	3 (3)	5 (5)	4 (4)
Shortened prosthesis	0	0	2 (2)	2 (2)
Soft-tissue inflammation	1	2 (2)	3 (3)	5 (5)
Implant loss after connection	0	0	13 (6)	4 (4)
Other problems	1	1	5 (5)	7 (6)

Prostheses level statistical comparison to the control group; no statistical significances registered ($p > .05$); except for: $p < .001$. Screw site fillings at time period 0 to 5 years.
*Treatment: adjustment in mouth.
†Treatment: adjustment at the laboratory.

presented in Tables 9 and 10. No differences in bone levels and bone loss were seen on patient level ($p > .05$). Overall mean marginal bone loss after 10 years was 0.7 mm (SD 0.77) and 0.6 mm (SD 0.57) in the test and control groups, respectively ($p > .05$). In total, 33.7% and 46.2% of the implants in the test and control group did not present any bone loss at all during 10 years in function, respectively. Only 2.9% and 1.4% of the implants in the test and control groups presented more than 3.1 mm bone loss (maximum 5.0 mm) after 10 years of follow-up, respectively. Differences with more bone loss for smokers than for nonsmokers was present at 1-year follow-up ($p < .05$) but not for the later time intervals ($p > .05$).

DISCUSSION

The results of this 10-year follow-up study showed an overall good treatment result indicating similar clinical and radiological performances for the two groups of frameworks. Only one, none loaded, implant failed in the edentulous mandibles, and this low frequency of implant failure in the mandible is in accordance with other studies.[29,30] Accordingly, all implants lost after prosthesis placements were found in the maxilla ($p < .05$). This pattern of more implant failures in the maxilla is also in accordance with other studies.[26,31,32] Another observation that corroborates other studies is that implants may occasionally be lost in clusters in the maxilla.[6,33] Thus, in this study, one patient in the test group lost all six implants, and thereby was the number of loose implants increased for this group of patients. However, no statistical significance was observed for patients ($p > .05$) which should be the level of analysis in these situations according to Herrmann et al.[34] As no statistical significant difference in implant survival between titanium and cast frameworks has been shown in other earlier comparable studies,[3,9,29] and no other signs of biological different response to titanium frameworks have been observed in this study, the present cluster pattern may be more related to patient characteristics such as smoking habits, which have shown to significantly increase implant failures, as also reported in other studies.[33,35]

TABLE 6 Distribution of Reported Number of Problems (Prostheses Within Brackets) in the Mandible Related to the Computer Numeric Controlled (CNC) (Test) or Gold-Alloy (Au) (Control) Groups During Different Time Intervals

Years	5 to 10 Years		0 to 10 Years	
Prostheses	CNC	Au	CNC	Au
Prostheses at start/end of time intervals	38/22	25/20	44/22	31/20
Number of observations (number of prostheses)				
Mechanical problems				
Loose prosthesis	3 (1)	0	3 (1)	0
Implant component fracture	2 (1)	0	2 (1)	0
Framework fracture	2 (2)	0	2 (2)	0
Veneer fracture: uncomplicated*	0	0	1	2 (2)
Veneer fracture: severe†	0	1	1	1
Wear of acrylic teeth	5 (4)	3 (3)	7 (4)	3 (3)
Loss of screw site filling	0	1	4 (4)	7 (5)
Biological and prosthesis problems				
Shortened prosthesis	1	0	1	0
Soft-tissue inflammation	2 (2)	2 (2)	7 (6)	4 (4)
Other problems	0	2 (1)	8 (7)	7 (6)

Prostheses level statistical comparison to the control group; no statistical significances registered ($p > .05$).
*Treatment: adjustment in mouth.
†Treatment: adjustment at the laboratory.

The average bone loss during the follow-up period was low and similar for the two groups, and well in accordance with earlier studies on turned surfaces implants.[29,31,36,37] Today, it is not possible to discuss the response to implants in this study with the roughened surfaces implants because of the limitations of 10-year follow-up studies in this field. Statistical differences of bone loss could be observed between smokers and non-smokers after one but not after 10 years of follow-up. Accordingly, this result could confirm earlier reported correlations between bone loss and smoking habits[36] after one but not at later time intervals. The observation of a continuous bone loss indicating a possible "peri-implantitis"[38] was rare in the present study, an observation that is in accordance to some reports,[39] but not to others that indicate higher prevalence of situations with more severe bone loss.[40]

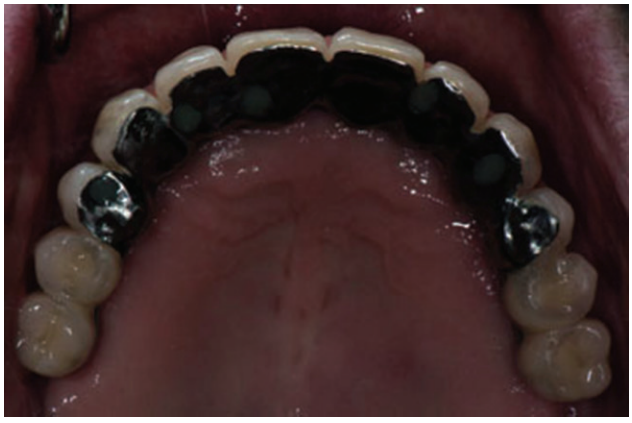

Figure 2 CNC-milled titanium framework with an "occlusal metal table" in titanium from first bicuspid on the right side to the first bicuspid on the left side.

Laser-welded titanium frameworks have shown significant problems with framework fractures related to the welding joints.[3,9,29] The present results report two fractures with the titanium one-piece technique and two fractures in the gold-alloy frameworks. Accordingly, the risk of fractures of the titanium frameworks is clearly reduced by replacing the older laser-welding procedures with a one-piece milling technique. Also, compared with fractures of cast frameworks, this CNC milling procedure compares favorably and it is easier to increase the dimension of the inexpensive titanium framework material to provide frameworks with greater dimensions than for more expensive gold-alloy frameworks. A possible side observation could be that with greater dimensions it allows for deeper screw access holes with better retention in CNC frameworks which reduce the risk of loose access hole fillings ($p < .05$; after 5 years).

TABLE 7 Mean Marginal Bone Levels in Relation to Fixture-Abutment Junction (FAJ) in the Maxilla in the Computer Numeric Controlled (CNC) (Test) and Gold-Alloy (Au) (Control) Groups

	Examined Prostheses and Implants			
	Baseline		10 Years	
Examined	CNC	Au	CNC	Au
Prostheses	22	31	12	17
Implants (x-rayed)	140	200	76	116
Marginal bone level in relation to FAJ (mm)				
Overall mean	1.65	1.67	2.28	1.96
Overall SD	0.46	0.66	0.80	0.59
Bone level (mm)	Distribution of number of implants (%)			
0.0 to 0.8*	29.3	37.5	11.8	19.8
0.8< to 1.9 (To thread #1)	47.9	38.0	28.8	33.6
1.9< to 2.5 (To thread #2)	16.4	12.5	19.7	32.8
2.5< to 3.1 (To thread #3)	4.3	6.5	18.4	7.8
3.1< to 3.7 (To thread #4)	0.7	3.5	18.4	3.4
3.7< to 6.1	1.4	2.0	2.6	2.6

Percentage of distribution of implants in each bone level interval is given.
Patient level statistical comparison to the control group; no statistical significances registered ($p > .05$).
*Implant reference point is placed 0.8 mm below FAJ.

Few mechanical problems were recorded for the implant components, observations that compares favorably with other studies.[29,30] Fractures of resin veneers were more common in the upper jaws for both groups, also reported earlier as a common problem.[3,31,41] However, early experiences with titanium frameworks have shown significantly higher problems with veneer fractures as compared with gold-alloy frameworks.[3]

TABLE 8 Mean Marginal Bone Levels in Relation to Fixture-Abutment Junction (FAJ) in the Mandible in the Computer Numeric Controlled (CNC) (Test) and Gold-Alloy (Au) (Control) Groups

	Examined Prostheses and Implants			
	Baseline		10 Years	
Examined	CNC	Au	CNC	Au
Prostheses	44	31	21	18
Implants (x-rayed)	214	158	102	92
Marginal bone level in relation to FAJ (mm)				
Overall mean	1.21	1.16	1.85	1.67
Overall SD	0.36	0.43	0.77	0.56
Bone levels in mm	Distribution of number of implants (%)			
0.0 to 0.8*	55.1	63.4	24.5	31.5
0.8< to 1.9 (To thread #1)	37.9	30.4	47.1	43.5
1.9< to 2.5 (To thread #2)	5.6	4.4	14.7	14.1
2.5< to 3.1 (To thread #3)	0.9	1.3	5.9	7.6
3.1< to 3.7 (To thread #4)	0.5	0.6	2.0	1.1
3.7< to 6.0	–	–	5.9	2.2

Percentage of distribution of implants in each bone level interval is given.
Patient level statistical comparison to the control group; no statistical significances registered ($p > .05$).
*Implant reference point is placed 0.8 mm below FAJ.

TABLE 9 Mean Marginal Bone Loss at Implants in the Maxilla of the Computer Numeric Controlled (CNC) (Test) and Gold-Alloy (Au) (Control) Groups

	Examined Prostheses and Implants							
	0 to 1 Year		1 to 5 Years		5 to 10 Years		0 to 10 Years	
	CNC	Au	CNC	Au	CNC	Au	CNC	Au
Prostheses	20	28	16	22	12	17	11	17
Implants	125	181	101	146	76	116	70	116
Mean marginal bone loss (mm) during function								
Overall mean	0.38	0.35	0.25	0.13	0.29	0.16	0.70	0.49
Overall SD	0.34	0.29	0.36	0.18	0.36	0.31	0.61	0.63
Bone loss (mm)	Distribution of number of implants in percentage							
≤0.0*	52.0	49.2	68.3	72.6	50.0	67.2	24.3	50.9
0< to 0.6†	25.6	22.7	21.8	17.8	28.9	21.6	32.9	19.0
0.6< to 1.2	15.2	22.7	5.9	8.9	13.2	6.9	20.0	11.2
1.2< to 1.8	6.4	5.5	4.0	0.7	7.9	2.6	14.3	12.1
1.8< to 2.4	0.8	–	–	–	–	–	2.9	3.4
2.4< to 3.1	–	–	–	–	–	1.7	5.7	2.6
3.1< to 3.6	–	–	–	–	–	–	–	0.9

Distribution of individual implants with regard to degree of bone loss (mm).
Patient level statistical comparison to the control group; no statistical significances registered ($p > .05$).
*A bone gain was detected in 8 implants in the Test and in 31 implants in the Control group between 0 to 10 years in function, here registered as 0.0 mm.
†Distance between the threads of the implants is 0.6 mm.

TABLE 10 Mean Marginal Bone Loss at Implants in the Mandible of the Computer Numeric Controlled (CNC) (Test) and Gold-Alloy (Au) (Control) Groups, and Distribution of Individual Implants with Regard to Degree of Bone Loss (mm)

	Examined Prostheses and Implants							
	0 to 1 Year		1 to 5 Years		5 to 10 Years		0 to 10 Years	
	CNC	Au	CNC	Au	CNC	Au	CNC	Au
Prostheses	44	28	37	24	21	18	21	18
Implants (x-rayed)	214	143	180	118	102	92	102	92
Mean marginal bone loss (mm) during function								
Overall mean	0.36	0.44	0.17	0.35	0.23	0.08	0.67	0.63
Overall SD	0.31	0.37	0.30	0.44	0.32	0.13	0.85	0.52
Bone loss (mm)	Distribution of number of implants in percentage							
≤0.0*	49.5	43.3	69.4	61.9	59.8	71.7	40.2	40.2
0< to 0.6†	22.4	26.6	17.2	18.6	20.6	19.6	17.6	20.7
0.6< to 1.2	24.8	22.4	8.9	10.2	14.7	6.5	23.5	20.7
1.2< to 1.8	2.3	6.3	3.3	7.6	2.9	1.1	8.8	10.9
1.8< to 2.4	0.5	1.4	1.1	0.8	2.0	1.1	3.9	5.4
2.4< to 3.1	0.5	–	–	–	–	–	1.0	–
3.1< to 5.0	–	–	–	0.8	–	–	4.9	2.2

Patient level statistical comparison to the control group; no statistical significances registered ($p > .05$).
*A bone gain was detected in 18 implants in the Test and in 11 implants in the Control group between 0 to 10 years in function, here registered as 0.0 mm.
†Distance between the threads of the implants is 0.6 mm.

Still, improvement of the supra construction whatever metal has been used has to be made with better acrylic resin matrix and inter-occlusal metal on the palatal side in the upper jaw on patients with overloading and grinding. Thus, in the light of present data trends of improvement with lower incidence of framework fractures[42] and few complications and maintenance appointments indicate a future with a further better control of the few present remaining clinical problems presented mainly in the maxilla such as veneer fractures for this treatment modality.

CONCLUSION

Within the limitations of this study, the CNC technique for milled titanium framework (Procera® Implant Bridge) presents similar clinical and radiological performances as cast gold-alloy frameworks in the edentulous jaw during the first 10 years of function with few complications during the study period. The CNC-milled titanium frameworks can be used as an alternative in a long time perspective to cast framework fabrication for full arch implant supported prostheses.

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